

**The Impact of Cognitive Load on Volitional Running, Kayaking, Rock
Climbing and Arithmetic Tasks and the Effect of Fatigue on Risk
Perception**

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By

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“The mediocre teacher tells. The good teacher explains. The superior teacher demonstrates.

The great teacher inspires.” - William Arthur Ward

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“The supreme end of education is expert discernment in all things – the power to tell the good from the bad the genuine from the counterfeit and to prefer the good and the genuine to the bad and the counterfeit”– Samuel Johnson

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Chapter 1

1.1 A Brief History of Physical Activity/Cognition Research

Exercise researchers have long focused on positive cognitive effects during acute bouts of physical activity. Faster reaction times and the release of neurotransmitters that result in positive emotions are typically found after exercise (Dietrich & Audiffren, 2011). More recently interest has grown in testing detriments to cognitive capacities during bouts of physical activity. Interestingly, researchers started noting negative psychological effects occurring during physical activity (Labelle, Bosquet, Mekary, & Bherer, 2013). In particular in dual tasks where people perform a cognitive task concurrently with physical activity, performance on the cognitive task is reduced relative to an appropriate control (Blakely, Kemp, & Helton, 2015; Darling & Helton, 2014; Epling, Blakely, Russell, & Helton, 2016; Green, Draper, & Helton, 2014; Green & Helton, 2011; Woodham, Billingham, & Helton, 2016). The interaction between physical activity and cognitive task performance is complex, with two general mechanisms resulting in potentially opposing effects: arousal -induced resourcing and direct resource competition (Dietrich & Audiffren, 2011; Lambourne & Tomporowski, 2010; Tomporowski, 2003; Tompprowski & Ellis, 1986).

A mechanism by which physical activity may result in improvements in cognitive task performance is energetic arousal. Increased arousal improves cognitive task performance, independently of physical activity (Helton et al., 2010; Helton, Matthews, & Warm, 2009; Langner, Willmes, Chatterjee, Eickhoff, & Sturm, 2010; Matthews et al., 2010; Matthews & Davies, 2001). Physical activity also increases global cortical arousal that results in availability of more cognitive resources (Lambourne & Tomporowski, 2010). In support of this, researchers have found improvements in simple reaction time tasks and speeded visual

search tasks during physical activity (McMorris & Graydon, 1997; McMorris & Hale, 2012; Shields, Larson, Swartz, & Smith, 2011).

At the same time, physical activity and concurrent cognitive tasks may create interference by competing for attention and a limited supply of cognitive resources. Researchers use dual task paradigms to test this interference; the dual task cost is evident when one or both of the tasks shows a decline in performance. In laboratory experiments that typically employ two concurrent cognitive tasks, dual-task costs to either tasks are common (Helton et al., 2010; Helton & Russell, 2011; Wickens, 2008). Dual-task costs are also found when whole body movement is combined with cognitive tasks and can effect performance on either or both tasks (Blakely et al., 2015; Darling & Helton, 2014; Epling et al., 2016; Green et al., 2014; Green & Helton, 2011; Head et al., 2016; Woodham et al., 2016) Such effects are typically greater when the two tasks are more challenging, requiring greater executive resources (Labelle et al., 2013). Indeed, in a recent meta-analysis, Lambourne and Tomporowski (2010) found greater cognitive task performance costs in studies with upright gait (walking or running) compared to cyclical movements (exercise bike) which may be due to the greater attention demands of balance and volitional control during upright gait maintenance. However, Mehta and Agnew (2012) also found dual-task costs between concurrent mental and physical demands during hand grip tasks, so the issue remains controversial. Kubitz & Pothakos, (1997) found an increase in alpha waves (indicative of a decrease in brain activity), particularly in the frontal cortex, following as well as during cyclical physical activity. This suggests that there may be some residing detrimental effects to cognition after exercise also. Contradictory findings regarding the cognitive effects of acute physical activity may be expected given the variety of cognitive tasks involved, the differing durations and levels of exertion required by the physical tasks, and the varying levels of fitness of participants,. However, even experiments that have controlled task, and personal variables produce

differing results (Dietrich & Audiffren, 2011; Labelle et al., 2013). This makes it difficult to isolate the cerebral processes and substrates activated while exercising, particularly, the role of the frontal cortex and executive function during physical activity which leads us to behavioural based research (Labelle et al 2013). Natural, unconstrained movements also require volitional control and are, therefore, subject to the desire or ability to maintain physical effort (Marcora, Staiano, & Manning, 2009). The function of volitional control and ecological activities are of particular interest due to their application to many occupations and sports.

1. 2 Theories of Attention

Structural Theory (bottleneck)

Experiments performed during the 1950's and 1960's led to the conclusion that attention was severely limited, typically allowing for performance of only one task at a time (Kahneman, 1973). Researchers theorised about the source of this apparent limitation in human information processing. Structural theorists thought that at a certain stage in perception, the ability to process information in parallel ceased, eventually narrowing to a single system, where a bottleneck occurred resulting in the completion of only one task at a time. One approach supposed that the bottleneck occurred at the perceptual stage (early-selection) while others proposed that limitations occurred at a response decision stage (late-selection) (Wickens, 1984). According to the bottleneck theory there is a dedicated decision making, response selection mechanism. The basic premise of this theory was that when two tasks competed at the response-selection stage, only one could make it through the bottleneck and therefore only one response at time was possible. Structural (i.e. bottleneck) theorists account for the greater detriment to performance in difficult dual-tasks by assuming that more

difficult tasks tied up the single system for longer (Wickens, 1984). Welford (1967), a proponent of single channel theory, concluded that deteriorated attention is the result of two tasks competing for control at the response-selection phase. This bottleneck results in only one response at a time being possible (Kahneman, 1973). Contrasting with structural/bottleneck theories are capacity theories. In these capacity theories, theorists propose a pool of processing resources which can be shared and allocated among competing tasks thus allowing completion of multiple tasks simultaneously, provided there are sufficient resources to support their performance at least to some degree. Interference between tasks is reflective of the effort required to perform the tasks or their difficulty levels (Kahneman, 1973).

Central Resource Capacity Theory

Central to the capacity theory is that attention and volitional effort have a single limited capacity central processor. This processor must be engaged for mental operations like response selection, mental transformation or rehearsing (Wickens, 1984). The limit of this capacity is expressed in terms of interference and it is stated that some degree of interference will occur between any two tasks. It also states that the extent of the interference will depend on the load imposed by each of the activities (Kahneman, 1973). Experimental support for this phenomenon is overwhelming, even presumably automatic tasks like walking or driving interfere with other cognitively demanding tasks (McFadyen, Hegeman, & Duysens, 2009; Oviedo-Trespalacios, Haque, King, & Washington, 2016; Plummer, Zukowski, Giuliani, Hall, & Zurakowski, 2015). The results from an experiment using a dual reaction time/basic counting task revealed that when tasks were easy there was an improvement in speed but when the tasks were difficult there was a marked decline (Keele, 1967). More recent supporters of this theory have proposed that the human information processor depends on the higher level executive system (Wickens, 1984).

Resource theory is measured using the dual-task paradigm. When two tasks are performed simultaneously it is assumed that the participant will prefer one of the two tasks and therefore is modulating the supply of resources (Wickens, 1984). Simply defined when changes occur in performance with added or depleted resources, the task is resource limited (Wickens, 1984). The performance resource function is used to describe the basic premise of resource theory and states that quality of performance is a function of resources invested until the person reaches the resource limit. At this point no further improvement is possible, and when performance changes with added or depleted resources the task is considered resource limited (Wickens, 1984). However it has been observed that some tasks do not appear to use the same cognitive processing resources, suggesting there are instead multiple resources acting in parallel which lead to the development of multiple resource theory (MRT).

Multiple Resource Theory

According to the multiple resource theory there is more than one commodity in the human processing system that is assigned resource properties like allocation, flexibility and sharing (Wickens, 1984). Knowles (1963) proposed that there existed a “pool” of different kinds of resource each limited in the capacity of its resources; as a task becomes more difficult, the availability of resources for other tasks decreases accordingly. This view proposes that unlike the bottleneck or single resource theory where one task is processed at a time, several tasks can be processed in parallel, in graded quantity. Instead of proposing that the single limited capacity central processor was required for mental operations it is instead more like several bottlenecks in the processing system (Knowles, 1963; Wickens, 1984). Taking account both behavioural and neurological findings Wickens (2008) proposed a multiple resource theory (MRT) that included three major dimensions or resources: stages of processing (perception, cognition, or action), codes of processing (spatial and verbal or

symbolic – subsequent studies would also suggest a separate object code), and sensory channels and modalities (visual, tactual, and auditory)(See Figure 1-1) (Wickens, 2008) .

When the performance requirements of concurrent tasks exceeds the maximum provision of a particular resource performance on one or more of the tasks will suffer (Wickens, 1984, 2008). Consideration of Figure 1-1 shows why some combinations of tasks are harder to complete concurrently than others.

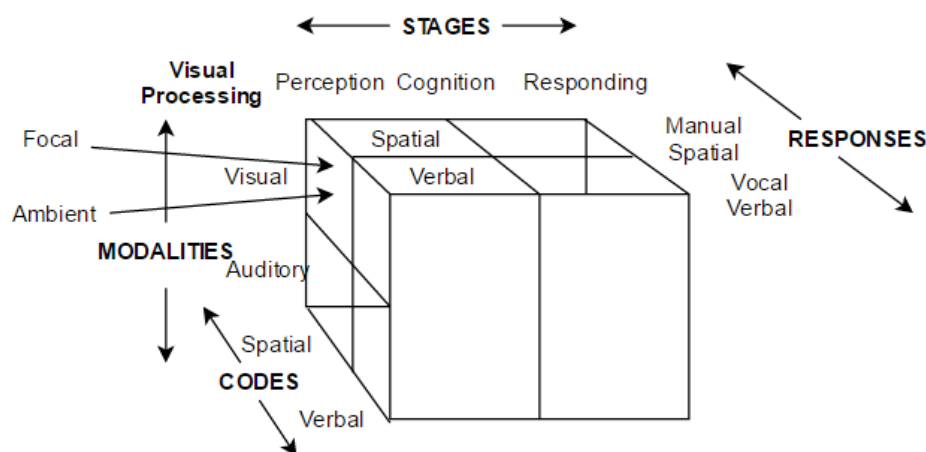


Figure 1-1: 3D explanation of attention resources

Stages of Processing

Perceptual and central processing rely on some resources that are common to both but which are separate to response resources (Wickens, 1984). When the difficulty in tasks is manipulated and this manipulation does not affect the performance on the concurrent tasks, it provides evidence of separate stages of processing. Several experiments have indicated that the effects of manipulating resource at encoding is independent of resource competition at

response (Vidulich & Wickens, 1981; Wickens, 1984; Wickens & Vidulich, 1982). This independence provides evidence for separate stages of processing resources.

Codes of Perceptual and Central Processing

Dual-task experiments using a verbal task and dowel balancing demonstrated that not only do verbal tasks draw on different resources than spatial tasks, but also that they are dominant in different cerebral hemispheres (McFadyen et al., 2009; Wickens, 1984). This asymmetry to handedness interference was reversed when spatial working memory was applied (McFadyen et al., 2009). There is deteriorated response when a verbal response is required for a verbal imaging task, or a manual response required for a spatial working memory task but when reversed, both are performed more efficiently (Brooks, 1968; Helton & Russell, 2011). Two tasks both predominately placing demands on spatial processing will interfere more than a task which is predominately verbal and one that is predominately spatial (Helton & Russell, 2011). When two perceptual processes, specifically two spatial targets are presented simultaneously, there is impaired performance, as opposed to when the spatial target is presented with a verbal target (Moscovitch & Klein, 1980). It is reasonable to conclude from these experiments that separate resources underlie verbal and spatial central processing, as well as encoding and response.

Modalities of Input and Response

The processing of modalities refers to visual and auditory channels and research in this area has focused on cross-modal presentation (Wickens, 1984). More efficient detection of both spatial-temporal patterns and semantic targets are evidenced in cross-modal compared to intra-modal presentation (Martin, 1980). This has also been found with time-sharing efficiency of tracking and discrete tasks using vocal and manual responses (Wickens & Vidulich, 1982). The interference observed in these experiments provides evidence that visual and auditory modes can be considered as distinct resources, there is also evidence for

tactile interference and hence a tactile resource (Brill, Gilson, & Mouloua, 2007). Nested within these resources is a fourth dimension, visual channels, used to differentiate between focal vision (used for reading text or symbols) and ambient vision (a part of peripheral vision and used to recognise movement) (Wickens, 1984, 2008).

The existence of different resource pools does not, however, contradict the notion of total resource demand (overall cognitive load) imposed by tasks. Even two tasks that do not overlap extensively may still result in interference if the overall demand of the two tasks is high. To some extent all tasks will overlap, however when two high demand tasks overlap in their use of resources, it may result in elevated competition and thus, interference.

There is also a prediction computational equation for the theory. The difficulty of two time shared tasks is either automated (0) easy (1) or difficult (2). The tasks are then compared within a 4-dimensional space and the extent to which tasks share common levels of each the four dimensions, (0, 1, 2, 3 or 4) (Wickens, 2008). This gives a total dual task interference ranging from 0-8 which can be used to predict the amounts of interference concurrent tasks are predicted to produce.

Full body physical activity is likely to place heavy demands on limited cerebral resources due to volitional control and the computationally demanding nature of movement. This has led researchers to formulate models similar to resource theory specifically for physical activity (Dietrich & Sparling, 2004; Dietrich & Audiffren, 2011).

Reticular Activation Hypofrontality Theory

Full body physical activity is likely to place heavy demands on the brain's limited resources and theories are developing to explain cognitive resource allocation during physical activity. A case in point is the reticular-activating hypo-frontality (RAH) model suggested by

Dietrich (2006). The RAH model has been developed to account for the largely contradictory finding in physical activity research and proposes that exercising results in generalised brain activation via the brain's arousal networks, but full body strenuous physical activity then forces the neural system to make economic trade-offs. Motion control, postural control including gait, volitional control and several emotional factors compound to make motion computationally demanding, the brain needs to redirect resources to cerebral processes most useful in controlling motor action (Dietrich and Audiffren 2011). For motor activity to be smooth and unhesitant, it should largely rely on the implicit (unconscious) cognitive system which some would describe as a 'flow state' (Swann, Keegan, Piggott, & Crust, 2012). Excessive control from the explicit (conscious) system may cause performance disruption (Beilock, Carr, MacMahon, & Starkes, 2002). The explicit cognitive system, which consists of working memory and deliberate executive control, entails extensive activation of the frontal cortex. The implicit system entails activity of more caudal areas of the pre frontal cortex, for example increased activity in the basal ganglia, cerebellum, and supplementary motor cortex (Dietrich & Audiffren, 2011). Thus, the RAH model proposes that intense physical activity should cause reduced frontal cortex activity and enhanced activity in more caudal parts of the brain. Regardless of the veracity of the RAH model, it plays an important role because it raises the issue of resource allocation during dual-task and multi-tasking situations that require full body locomotion (Dietrich and Sparling 2004). Indeed, like MRT, the RAH model also makes the point that the brain's processing systems may be construed as multiple interacting and potentially competing entities. Although this thesis does not test this theory explicitly by applying brain imaging research, it nevertheless addresses issues relating to the effects of strenuous physical activity on cognitive performance. This thesis can therefore contribute to the body of knowledge in the area of cognitive and physical task

performance, contributing to not only multiple resource theory but also theories developed specifically for physical activity.

1.3 The effects of concurrent physical and cognitive tasks

Runners typically experience positive emotions, analgesic and sedation effects, and feelings of wellbeing which last well into the post physical activity period (Dietrich & Audiffren, 2011). Post endurance physical activity shows a significant increase in euphoria coupled with increased opioid binding in the prefrontal cortex which provides an explanation for the ‘runners high’ (Boecker et al., 2008; Dietrich & Sparling, 2004). Due to experimental and technological constraints, these effects can be tested only after the physical activity. Little is known about cognitive processes that occur during physical activity. Until recently the commonly held view has been that physical activity has positive cognitive effects, however reviews of physical activity literature demonstrates many contradictory findings (Dietrich & Audiffren 2011). Dietrich & Audiffren’s (2011) review reveals that while many positive cognitive effects are observed in the period following engagement in strenuous physical activity, strenuous activity itself may actually impair concurrent cognitive performance suggesting that the functioning of prefrontal regions may be impaired during physical activity.

The interaction between physical activity and cognitive task performance is complex with two general mechanisms resulting in potentially opposing effects: arousal-induced resourcing and direct resource competition (Dietrich and Audiffren 2011; Lambourne and Tomporowski 2010; Tomporowski 2003; Tomporowski and Ellis 1986). As one system is boosted, another is weakened. For this reason behavioural science methods are used to establish to cognitive performance during concurrent physical activity. Many of the studies

investigating the effects of concurrent physical activity on cognitive processing activities such as treadmill walking and running, or stationary cycling that are typically cyclical and occur in totally predictable constrained artificial environments (Lambourne and Tomporowski 2010). While employing a constrained movement task has merits, for example safety and ease of data collection, this unfortunately may reduce the cognitive costs of physical activity-locomotion below those likely to occur in more realistic settings. Full body locomotion in natural environments is not simply a matter of exercise and physical load, but also requires dexterity and motor planning to deal with obstacles and surface variation and the suppression of interfering environmental factors like wind. Anyone who has run on a treadmill and then run outside on a trail is aware of this difference, in fact indoor exercising actually allows the user to divide their attention, for example some people may read or reply to emails while on the treadmill or Exercycle. This is not likely to happen in ecological settings due to risk of falling and the dynamic nature of the environment. The physical tasks in the following experiments are ecological in nature and are intentionally field based tasks to establish the full extent 'real life' environments have on cognitive load.

Some research highlighting the negative psychological effects occurring during physical activity has however, been conducted (Labelle et al., 2013). These researchers found the intensity of the physical activity increased, decrements in cognitive performance, increased and this was more pronounced in unfit individuals. There is little research where current technology allows researchers to accurately measure cerebral activity while in motion (Mehta, Parasuraman, Mckendrick, Ayaz, & Scheldrup, 2015). The movement created by running or other physical activity while using a portable fNIRS creates a movement artefact which means the results may be due to the runner moving as opposed to the blood flow actually changing in the pre frontal cortex. It should also be noted that both

studies involved a stationary bike; the effects they observed may be even more pronounced had ecologically real physical tasks like a hilly downhill mountain bike track been used.

Other researchers have examined the interaction between dual- task physical activity and cognitive tasks in activities like rock climbing (Darling & Helton, 2014; Green et al., 2014; Green & Helton, 2011; Woodham et al., 2016) Climbing distance was not reduced by a concurrent memory task but memory performance was significantly reduced by climbing. This suggests a prioritization of processing resources towards climbing probably because climbing error has more painful consequences (e.g. falling) than failure in a laboratory memory task. Ecological running has also been used in dual task paradigms with interesting results; performance on easy cognitive tasks appears to be enhanced during concurrent running whereas concurrent running reduces performance for more difficult cognitive tasks. Running performance in Blakely et al (2015) showed a linear decreasing trend in performance; however responses were given by tapping a smartphone interface which may have created peripheral interference. Interestingly dual task experiments using two physical tasks show declines in performance on both tasks similar to that of the cognitive task/physical task paradigm task performance decrement; as well as a decline in dual task performance as age increases (Corp, Rogers, Youssef, & Pearce, 2016; Voelcker-Rehage & Alberts, 2007).

Modifications of the Kennedy tone counting task (Kennedy & Bittner, 1980) were used in the experiments presented in this thesis because this task allows ready manipulation of cognitive load and difficulty level (Kennedy & Bittner, 1980). The task also minimises the amount of non-central interference between cognitive task and physical activity dependent on vision (Brill et al., 2007). It is expected that dual-task interference costs; errors in tone counting accuracy, and/or reduced physical task performance, will increase as the difficulty of the tone counting task increases. In addition, self-reports of workload and stress will be collected and collated using a modified version of the NASA-TLX. The aim is to examine

whether subjective workload increases as the difficulty of the combination of tasks increases. Experiments measuring physical activity and dual task costs typically take physiological measurements (e.g. Heart rate) to ensure physical effort is sustained. As mentioned previously, the majority of research on dual-task effects during physical activity use constrained laboratory physical activity (treadmills and cycle ergometers). This work has some significant advantages (increased experimental control of the running task). The present research, however, takes a different approach to the problem and starts in the wild with fully ecologically realistic tasks. The goal is to eventually have both, constrained physical activity research and unconstrained ecologically realistic research, because together they should clarify the role of whole body motion on cognitive resource allocation. Due to the executive cognitive processes affected by physical activity it would be prudent to include a variety of other cognitive processes also. During physical activity, many decisions are calculated and made, specifically in physically risky tasks where the person may come to harm. Accurate perception of risk could not only be impaired by reduced allocation of resources but by cognitive and mental fatigue which it is expected to increase the longer the strenuous physical activity has been undertaken.

1.4 Introduction to Risk Perception

Risk perception is a subjective risk estimation made about how something in an environment could bring an individual to harm (Breakwell, 2014). It refers to the identification, quantification and characterisations of threats from the environment and hazards (Slovic & Weber, 2013). These perceptions play a role in decision making and responses depend on whether it is a long term risk or an in situ risk. Long term risk perception is influenced by many things; political, cultural, economic and psychological

theories come into play to explain decisions and actions for a threat (Wildavsky & Dake, 1990). Risk assessment and risk perception can be divided into separate processes, although it is argued both are considered subjective to some degree (Breakwell, 2014). Risk assessment is something we all do on a daily basis, while driving we assess the risk of crossing traffic and not causing a collision, sports people assess the risk of injury against performance, and even choosing to carry an umbrella due to the risk of rain (Breakwell, 2014). Formally, risk assessment seeks to systematically evaluate and estimate risk and can be divided into risk estimation and risk evaluation which helps us manage risk outcomes (Breakwell, 2014). This thesis, however seeks to address risk perception in an individual, in situ. Within the individual there are widely reported heuristics and biases that develop in order to make sense of an uncertain world (Slovic, 2004). These biases influence the way an individual sees the world and these initial beliefs seem to outweigh the presence of evidence, and influence the way subsequent information is interpreted (Slovic, 2004). Risk perception occurs when we are required to make judgements under conditions of uncertainty (Tversky & Kahneman, 1973). Instead of assessing the probabilities of uncertain events and predicting the values of uncertain quantities, people rely on heuristic principles to reduce the complexity of everyday in situ risk perception (Breakwell, 2014; Tversky & Kahneman, 1973). Heuristics are effective and economical but lead to errors and biases in the perception of risk. The way we make decisions is extremely complex; there is both an emotional, intuitive and fast system as well as the deliberate and more logical system. These systems both assist decision making and risk perception but also create biases and errors in judgement, the heuristics are used when we need to make fast decisions (Breakwell, 2014; Tversky & Kahneman, 1973).

As well as relying on heuristics and biases there are noted differences in risk perception between gender and varying emotional states (Sjoberg, 2000). Some cognitive states can be influenced by our environment, while participating in physical activity or sports

we may become fatigued. This fatigue may change our perception of risk. There is both anecdotal and experimental evidence that fatigue affects cognitive processes and slows down physical performance. Mosso (1904) reported his reluctance to participate in sport after a mentally strenuous and this mental fatigue could impact physical performance. As an example, boulder hopping in trail running is a risky behaviour and when the runner is fatigued they may assess the risk as greater and therefore jump conservatively based on this assessment, in turn being less efficient and slower. It is apparent in many physical activities how cognitive function effects perception of risk and subsequent physical performance.

1.5 Introduction to Fatigue – cognitive and physical

Fatigue can be defined in terms of mental or physical exhaustion. The effects of mental fatigue on cognitive processes, like attention has been well documented (Guo, Chen, Zhang, Pan, & Wu, 2016). Mental fatigue is defined in many ways; it has been described as a psychobiological state caused by long periods of cognitive work and subjective feelings of being tired (Marcora et al., 2009). More specifically the neuroergonomic approach suggests that neural interference at the prefrontal cortex (PFC) may influence physical fatigue development during tasks that are associated with high cognitive demands (Mehta & Parasuraman, 2013). Experiments using functional near infra red spectroscopy (fNIRS) and EEG to measure oxygenation of blood flow in the PFC have shown that as time on a physical task increases, PFC oxygenation decreases (Liu, Zhang, & Zheng, 2010; Mehta & Parasuraman, 2013). This suggests that as time passes during physical tasks the ability for top-down commands from the PFC decreases potentially creating what is thought of as physical fatigue (Mehta & Parasuraman, 2013).

There is consensus that muscular fatigue is at least partially due to a critical reduction in PFC deoxygenation (Mehta & Parasuraman, 2013). Marcora (2009) reported that after a 90 minute cognitively fatiguing task, participants' time to fatigue on a stationary bike was reduced,; they became tired faster compared to the control group (no cognitive fatigue) (Marcora et al., 2009). Marcora et al (2015) also found that mental fatigue reduces performance and increases perception of effort in intermittent running performance as time goes on. They conclude that the perception of effort is the mediating factor, in other words when participants felt tired they performed worse suggesting that cognitive fatigue led to the observed impairment in performance (Smith, Marcora, & Coutts, 2015). Kempton and colleagues (2008) used time motion cameras to monitor performance in rugby league players and found that as time increased the physical endurance and performance as well as the technical skill of players decreased (Kempton, Sirotic, Cameron, & Coutts, 2013). Not only is there muscular fatigue but technical skills decrease suggesting mental fatigue is effecting their ability to carry out technical movements, potentially a break-down of the top-down processing due to limited resources in the PFC (Mehta & Parasuraman, 2013).

Certainly mental fatigue appears to affect consequent physical performance however the underlying reasons for this are still not clear. As cognitive fatigue sets in, reduced cortical arousal results in a diminished allocation of resources for the maintenance of task performance. In this case other executive cognitive functions, such as risk perception, should change in some way either becoming more conservative or rasher due to less access to processing resources.

1.6 Risk Perception and Fatigue

Risk perception and cognitive fatigue

From as early as 1891 Mosso wrote about his mental fatigue affecting his later physical performance because he thought he was tired. He shared this phenomenon with his fellow professor's; after a hard day lecturing, he was more physically fatigued even though he had not exerted himself physically at all (Mosso, 1904).

Cognitive fatigue has been shown to affect risk taking behaviours in gamblers in a different way (Frings, 2012). Sleep deprivation is potentially a form of ecological cognitive fatigue; it did not change the risk perception of fatigued gamblers in situ, instead it was found that both fatigued and not fatigued groups rated high risk bets as just as risky (Frings, 2012). However, the fatigued participants did not reduce their wager to accommodate the greater risk of bets, instead they realised the increased risk but did little about it (Frings, 2012). Venkatraman et al (2007) found during a fatigue gambling experiment, both frontal cortex activation was reduced (consistent with cognitive fatigue) and right nucleus accumbens activation was elevated (consistent with increased risk seeking behaviour) (Venkatraman et al., 2007). This confirms participants were cognitively fatigued and that their perception of risk changed based on their mental state, specifically they were less sensitive to loss than the control group. We know that mental fatigue affects risk perception, and while sleep deprivation isn't the same as vigilant cognitive fatigue which will be tested in this thesis, the gambling research is used to outline the apparent change to risk perception when cortical regions are fatigued. Furthermore the authors propose that mental fatigue (vigilance induced) will in fact create a greater risk perception as proposed by Mosso.

Risk perception and physical fatigue

Risk perception is a cognitive function that may be affected by physical activity and physical or mental fatigue. It appears that risk perception is affected by cognitive fatigue but it is also worth noting the changes in risk perception after physical fatigue. Cyclists and endurance runners were given a risk perception scale to complete, and then record their expected pace prior to completing an acute bout of cycling and a 100km endurance run. Athletes who were low risk perceivers, went faster than the high risk perceiver and if they were a high risk taker they went faster than the low risk taker (Micklewright et al., 2015). This shows that high risk takers may not perceive risk the same as high risk perceivers, resulting in more risky behaviour which did affect the way athletes pace themselves (Micklewright et al., 2015). Although this is measuring trait as opposed to state risk perception it demonstrates how risk perception and physical performance interact, and it would have been interesting to administer this questionnaire after their bout of exercise as well as before.

Risk perception is not fully understood, and encompasses multi-dimensional factors, several different definitions and can differ based on immediacy of action (Kahneman & Lovallo, 1993; Sjöberg, 2000; Slovic, Peters, Finucane, & MacGregor, 2005; Tversky & Kahneman, 1986). From an evolutionary perspective as one's ability to perform physically and mentally decreases, it makes sense to adopt a mentally conservative approach, "if I jump that gap I will make it" as opposed to "I'm tired and might fall if I jump over that gap". Resources are not allocated to the whole brain at all times and the human system has developed in order to employ utility to decide on allocation (Navon & Gopher, 1979). Perception of risk has surely evolved in order to keep us physically safe, when our cognitive and subsequently physical resources are depleted.

Contrary to this perspective there is evidence (in driving) that fatigue increases risky behaviours (Paterson, Browne, Ferguson, & Dawson, 2016). Fatigue from sleep deprivation and driving shows regardless of risk, tired drivers are still likely to drive. (Paterson et al., 2016). This acceptance of risk is also evident in smokers and sunbathers (Breakwell, 2014). In risk perception experiments, Rosenbloom and colleagues (2011) found no difference in pedestrians assessment of risk while crossing a road, whether they were fatigued or not, (fatigue was not manipulated in experimental form, but rather was measured through a subjective questionnaire) (Rosenbloom, Beigel, & Eldror, 2011).

The perception of risk has been described using a three dimensional factor structure showing the interrelationship between the amount known about a risk and the dread of the risk (Slovic, 2004). This explains why there can be contradictory acceptances to risk. Risk perception is certainly a complicated executive function, dependent on immediacy of action/outcome, needs and desires, rules and heuristics that guide our behaviour. By applying the MRT to risk perception, when our mental resources are depleted it could deteriorate the heuristics of risk perception, which creates a more conservative approach to risk.

1.7 Risk perception in cycling

In New Zealand in 2015, 6 cyclists died, 145 were seriously injured and 600 suffered minor injuries in police-reported crashes on New Zealand roads. This is about 6 percent of casualties from police reported crashes in 2015. Cyclists have a number of risk factors, decreased stability and a much lower level of protection than provided by a car. These factors combined give cyclists a high level of risk per time unit travelled (Ministry of Transport NZ, 2016). It is evident that cycle commuting is a risky task and route safety and risk perception in cyclists is not always reflected by the actual risk (Winters et al., 2012). In fact, perception of risk is higher than the reality of risk (Frings, Rose, & Ridley, 2012; Winters et al., 2012).

In this thesis a risk questionnaire was created using pictures of potentially risky cycle-ways and participants were asked to rate responses to three questions about their perception of the pictures. This questionnaire will be used before and after both cognitively and physically fatiguing events to test the hypotheses that after a cognitively or physically fatiguing event, participants will view the pictures as more risky than before.

1.8 Structure of Thesis

The structure of this thesis may appear slightly different due to the chapters being a collection of publications at varying stages. For this reason chapters are presented as a collection of completed articles, however every effort has been made to avoid repetition and for each chapter to be a continuation of ideas from the previous. Chapter's two, three, four and five report dual task experiments using the same cognitive counting task with either, running, kayaking, climbing or a maths task. Chapter six presents the comparison of these tasks. Chapter seven is an experiment about how cognitive fatigue effects risk perception and chapter eight is a questionnaire study investigating risk perception, flow states and subjective mental and physical fatigue before and after a marathon. Finally chapter nine summarises the chapters and chapter ten provides a general discussion and conclusion.

Chapter 2 - The Impact of Cognitive Load on Volitional Running

2.1. Abstract

The effects of physical activity on cognition and the effects of cognitive load on physical activity are complex. Both the nature of the physical activity and the cognitive task may influence the interactive effects of performing a physical task concurrently with a cognitive task. In a previous study examining the impact of increased cognitive load on outdoor running speed and the impact of outdoor running on cognitive performance, Blakely et al (2015) found running speed decreased as cognitive load increased. They also found that the impact of running itself on cognitive performance occurred when the cognitive task was itself demanding (high cognitive load). In the current study we modified the experimental task in order to rule out peripheral sensory, not central or executive, interference and we also incorporated heart rate measures and VO₂ max estimates. Twelve runners completed five conditions, two seated cognitive tasks (one low load and one high load), two dual running cognitive tasks and one run only. Results were similar to the original experiment, as the cognitive task became more difficult, voluntary running speed decreased. Also the effects of running on cognitive performance (counting) were found only when the cognitive task was high load.

2.2. Introduction

The interaction between physical activity and cognitive task performance is complex. Previous research has examined the effects of acute physical activity on cognitive performance (Colzato et al., 2013; Darling & Helton, 2014; Draper, McMorris, & Parker, 2010; Labelle et al., 2013). Physical activity preceding cognitive performance appears beneficial to subsequent cognitive performance, reducing reaction times on cognitive tasks and increasing the release of feel good neurotransmitters (Dietrich & Audiffren, 2011). Researchers have also begun to examine the impact of challenging cognitive performance preceding later physical performance. In this case the researchers have found that mentally fatiguing tasks reduce subsequent physical performance (Marcora et al. 2009). This asymmetry of order effects is intriguing, but the focus of the current research is on the potential interactions that occur during concurrent performance of demanding physical and cognitive activities. Researchers investigating concurrent interactions employ dual-task paradigms where participants are required to perform a cognitive task while also performing physical activity. Many studies using a dual-task paradigm have demonstrated dual-task costs, a performance loss to one or both of the tasks (Labelle et al. 2013; Darling and Helton 2014; Green and Helton 2011; Green et al. 2013). Some studies do not report dual-task costs, but instead have found positive effects of simultaneous physical activity on concurrent cognitive task performance (McMorris, 2016; McMorris & Hale, 2012; McMorris, Sproule, Turner, & Hale, 2011; Shields et al., 2011).

The lack of dual-task costs or interference when some physical tasks are performed concurrently with a cognitive task may be due to the nature of the physical task itself (Lambourne & Tomporowski, 2010). Studies using artificial or simplified physical tasks, like stationary cycling, which place few demands on participants other than physical exertion itself, are less likely to report dual-task costs (Lambourne and Tomporowski, 2010). The

more the physical task puts perception and action coordination demands on the participant the more likely dual-task costs are reported; treadmill running is found to be more interfering than stationary cycling and running over natural terrain is probably even more interfering than treadmill running (Blakely et al.2015). Split-belt treadmill studies using the dual task paradigm show that asymmetrical walking creates greater interference with cognitive tasks than symmetric treadmill walking(McFadyen et al., 2009) . This may be due to the dynamic balance requirements of asymmetrical walking, by having to control limb loading and placement(McFadyen et al., 2009). This has direct applications for those with a limp or the elderly but can also be applied to more ecologically realistic running, as the route is not predetermined and dynamic balance is certainly of concern in natural settings.

Possible explanations for these interactive effects, both the positive and the negative, include arousal induced cognitive resourcing and direct cognitive resource competition (Dietrich & Audiffren, 2011; Lambourne & Tomporowski, 2010; Tomporowski, 2003; Tompprowski & Ellis, 1986). Arousal-induced resourcing improves cognitive performance, independent of physical activity (Helton et al., 2010, 2009; Helton & Warm, 2008; Langner et al., 2010; Matthews et al., 2010; Matthews & Davies, 2001). During physical activity, simple reaction time tasks and speeded visual search tasks show improvement, possibly due to extra resources that become available with increased energetic arousal (McMorris & Graydon, 1997; McMorris & Hale, 2012). This may explain the improved cognitive task performance during, and after physical activity, and helps explain why some facets of cognitive performance improve while others deteriorate during physical activity. Direct competition for attention and resources may also limit performance during concurrent physical and cognitive tasks. Dual task costs are found both in the laboratory while completing dual cognitive tasks and when combined with physical activity (Green et al., 2014; Green & Helton, 2011; Helton & Russell, 2011; Lindenberger et al., 2000; Wickens,

2008; Woodworth & Schlosberg, 1955; Yogev-Seligmann et al., 2010). The more difficult the two tasks are, the greater the competition for resources, resulting in more of an interference or dual-task cost (Labelle et al., 2013). Lambourne & Tomporowski, 2010 compared the dual task costs of treadmill running and cycling and found that the greater the attention demand of balancing on a treadmill compared to a stationary bike, the greater the cognitive task performance costs. Given that natural physical activity, such as self-paced running, places a high demand on attention due to volitional control and motor planning, the dual task costs can be explained using cognitive resource theory (Kahneman, 1973). In this theory, tasks compete for limited cognitive resources. Building on cognitive resource theory, which is broadly employed in psychology and cognitive neuroscience, multiple resource theory (MRT) incorporates several processing factors that provide an explanation for the results. There are also more specific resource-like theories for physical activity, for example, the reticular activation hypofrontality theory (RAH) (Dietrich and Sparling 2004; Dietrich and Audiffren 2011). Regardless of the veracity of these newer, more physical activity specific theories, the application or expansion of cognitive resource theory and MRT to physical tasks, as well as cognitive tasks, is warranted. Indeed, volitional control, whereby participants have to will themselves to maintain their physical effort may require attention and place demands on the frontal cortex which may be interfering with the simultaneous cognitive task (Mehta & Parasuraman, 2013). Research has shown that simultaneous resource competition can result in a decline in running speed (Blakely et al., 2015; Epling et al., 2016).

The current experiment follows from previous work which has examined running over varying natural terrain (steep hill track versus flat track) while the participants completed a cognitive task of varying cognitive load. Runners in the prior research were given a cognitive tone counting task with two levels of difficulty, while running (dual) and seated (control), for a set time. Distance run during a set time period and accuracy of tone

counting were measured. In the previous experiment overall running speed was affected by terrain type and cognitive load. Distance ran decreased as cognitive task difficulty increased and task accuracy was affected only in the hard running dual task condition (Blakely et al. 2015). However, this study had two limitations; first, in the original study the tone counting task that was employed required a manual response on a smart phone, consequently some of the dual-task interference may have been due to visual peripheral interference (the tone counting interface had a button to press as response), not central or executive cognitive interference. The runner may have looked at the cell phone when selecting a response to the tone-counting task and looking away from the running path may have been a source of dual-task interference. In the present study we wanted to rule out this potential peripheral or sensory interference and therefore, in the present design participants gave a verbal response to the tone counting task, thus there was no need to look away from the running path. Second, the original study included no measures of physical fitness and no physiological measures of physical exertion. An additional factor to consider was running intensity; Labelle (2013) found cognitive task accuracy differed based on intensity of physical activity. While it seems reasonable to assume competitive running participants are able to monitor their pace, no biometric measurements of physiological effort were previously taken. The addition of a heart rate measurement and field VO_2 max estimation tests will provide a physiological gauge of effort and measures of physical fitness and exertion.

Our hypothesis is that increased cognitive loading will decrease running distance. It is also expected that task accuracy will decrease in the hard high cognitive load dual task condition. Heart rate results will be synonymous with self-reported effort, with little difference in expended effort, and VO_2 max is expected to show participants have a good overall fitness level.

2.3. Method

2.3.1. Participants

Twelve athletes (five women; seven men) from multisport and running communities served as participants. Study inclusion was limited to people with normal or corrected-to-normal vision and hearing based on self-report and who ran a minimum of three days per week. Participants ranged in age from 22 to 55 years ($M = 32.8$ years, $SD = 10.7$). This experiment was approved by the University of Canterbury's Human Ethics Committee and all participants were treated in accordance with the ethical guidelines. Runners wore a safety helmet and their own shoes and clothing. Participants were compensated for their time with a shopping voucher.

2.3.2. Materials

VO₂ Max tests. Gender, age, body composition (height and weight) and a self-report physical activity level scale (PA-R Appendix A) were recorded to estimate VO₂ (maximal oxygen uptake; indicator of aerobic fitness). Information and consent forms were given (Appendix BB). A polar RX3 GPS heart rate monitor was fitted, including the watch, to monitor and record beats per minute (BPM). Participants were asked to jog for one mile (1.6 km) at comfortable pace, ensuring the males took no less than 8 min, and the females, no less than 9min. One mile equates to four 400m laps and nine metres. Their pace was monitored using a stop watch and reported every lap to ensure correct speed. Upon completion of the mile, time and heart rate were recorded. The 1-Mile Jog Test (George et al 1993) uses gender, weight, mile time and heart rate to calculate VO₂ max, but it has been tested using only fit college age students. The Jackson Non-Exercise Test (Jackson et al 1990) uses age, gender, body mass index (BMI) and the PA-R to measure VO₂ max with a reliability of $r=0.78$,

however it is not valid for use with fit college age students. VO₂ scores were all within good fitness level range.

	VO ₂ max Jacksons	VO ₂ max Mile	VO ₂ max average	Age	Gender
Participant 1	46.37	58.60	52.49	32	M
Participant 2	47.29	60.02	53.65	55	M
Participant 3	48.55	52.86	50.70	29	M
Participant 4	43.65	52.28	47.96	26	F
Participant 5	52.66	62.45	57.55	22	M
Participant 6	43.64	47.13	45.38	29	F
Participant 7	48.94	62.74	55.84	46	M
Participant 8	39.44	53.21	46.32	43	F
Participant 9	47.35	53.05	50.20	24	F
Participant 10	49.52	52.35	50.93	25	M
Participant 11	51.64	63.36	57.50	22	M
Participant 12	38.43	56.39	47.41	40	M

Table 2-1: Vo2 max results for the Jacksons and the One Mile tests

Tone counting task. A tone counting task was played to participants using an Iphone 4s, iPsymrt and RecorderApp v2.2.1 applications played through Triton Kamo headphones that were zip tied to the safety helmet (Appendix CC). The tone counting application is an adaption of the Kennedy counting task and is designed to tax working memory (Kennedy and Bittner 1980). Three tones were played (300Hz, 1100Hz and 2000Hz) through a headset with sound attenuating headphones and microphone for responses. The tones were played randomly (equal number of low, medium and high frequency tones) to participants for five minutes. There was a low load, high load and no load condition for the tone counting task. No

load meant participants heard the tones but were not required to respond to them (control). The low load condition required participants to count every fourth presentation of the low tone only and when they counted the fourth tone, state “low” into the mic and continue for the duration of the experiment. For the high load condition, participants counted every fourth of all three pitched tones consecutively and reported each fourth tone by stating “low” “mid” or “high”. When the fourth count was reached and reported, the count started again and continued until the task was completed. If participants miscounted or lost count they were asked to state the tone they lost count on and start the count again from there. A correct count was the presentation of four low tones and the participant reporting “low” on the fourth tone, or all three, low mid and high tones in the high demand condition. Only the low tone however was used for results purposes in the high load condition in order to have a consistent comparison for the low load task with the high load task. The tones were random equal number, with a total of 99 presentations, 3 second inter-trial interval, and tone duration of 500ms.

NASA TLX. A modified version of the NASA TLX (Appendix D) was employed which consisted of six scales: mental demand, physical demand, temporal demand, performance-monitoring demand, effort, and emotional demand (Hart and Straveland 1988; modified version Sellars 2013). The questionnaire was given to participants immediately following each task, when it was comfortable for them to complete it. The ratings vary from 0 – very low to 100 – very high.

2.3.3 Procedure

To limit fatigue and practice effects, participant task order was counterbalanced using a Latin square design for the three running conditions and the seated tasks were grouped

either before or after the running tasks due to ease of facilitation, meaning all participants had a different order.

Run alone condition. Participants ran on a flat 400m grass track (Figure 2-1). Participants were instructed to run as fast as they could for the duration of the five minute task. They wore a heart rate monitor and helmet as part of the listening/recording device. They were played the tone counting task but were instructed that they did not have to count any of the tones. Their distance was measured at completion.



Figure 2-1: 400m oval grass track

Seated counting task. For each of the two seated counting tasks, participants were seated on a bench in the field. They were instructed to count every fourth tone of just the low tone (low load) or all three tones (high load) for a five minute duration and respond using “high, mid or low” for the corresponding fourth tone. The participant initiated the start of each task using the “begin test” button on the cell phone interface which concluded after five minutes.

Dual tasks. The two dual task conditions combined the track running and the counting task. Participants received the same instructions for the tone counting task as in the seated trials. Self-reported recovery time was used to indicate the start of the next condition (heart rate was required to be at or below 100 bpm) before proceeding to the next run.

Participants started the tone counting task by pressing the 'begin test' button on the cell phone interface. The researcher started the stop watch at the same time and measured the runner's exact position on the track at five minutes (because runner's momentum doesn't stop exactly when the time is up). A marker was placed at the stopping point and all three distances were measured with a meter wheel at the end of the experiment. Participants were instructed to run as fast as they could and were not asked to prioritise either task. Upon completion of each condition the participants were given the NASA TLX questionnaire.

2.4 Results

2.4.1 Tone-Counting Performance

For each participant we calculated the percentage of times that the fourth low tone was correctly reported. Kolmogorov-Smirnov and Shapiro-Wilk normality tests were statistically significant for not just the individual measures of tone counting accuracy, but also for the differences between the respective single and dual task conditions, $p < .05$. We, therefore, compared the single-task and dual-task conditions for each difficulty level using nonparametric tests. For the one-frequency tone counting task there was no significant difference between the single-task (Mdn = 100.00%) and the dual-task (Mdn = 87.50%), $Z = 1.10$, $p = .272$, $r = .32$. The three-frequency tone counting task accuracy was significantly lower in the dual task situation than in the single-task Mdn = 93.75%, dual-task Mdn = 68.75%, $Z = 2.22$, $p = .026$, $r = .64$.

2.4.2 Running Performance

Kolmogorov-Smirnov and Shapiro-Wilk normality tests were not statistically significant for the measures of running distance (meters), $p < .05$. We, therefore, compared the running tasks using two orthogonal contrasts using paired t-tests. Our first test was between the running single-task with the average of the running tasks with the tone-counting task. There was a significant reduction in distance run in the dual task conditions, ($M = 1088.85$ m, $SD = 136.68$), compared to the running alone condition ($M = 1118.65$ m, $SD = 135.64$), $t(11) = 3.79$, $p = .003$, $M_{\text{difference}} = 29.80$ m, 95% CI [12.47, 47.12]. There was no significant difference between the running with one-frequency tone-counting ($M = 1100.45$ m, $SD = 143.86$) and the running with three-frequency tone-counting task ($M = 1077.25$ m, $SD = 133.81$), $t(11) = 1.62$, $p = .134$, $M_{\text{difference}} = 23.20$ 95% CI [-8.40, 54.80].

For descriptive purposes we also examined the decrease in running distance with increasing cognitive load (running alone – zero frequencies counted, one frequency and three frequencies counted). The slope of the line of best fit was found for each subject individually. The resultant slopes were averaged across individuals, $M = -13.48$, $SD = 12.46$, 95% CI [-20.71; -6.75]. The average line of best fit is displayed in Figure 2-2: The mean distance run (m) for the three tone frequency counting conditions: 0 frequency tones counted (single-task running), 1 frequency tones counted, and 3 frequency tones counted.

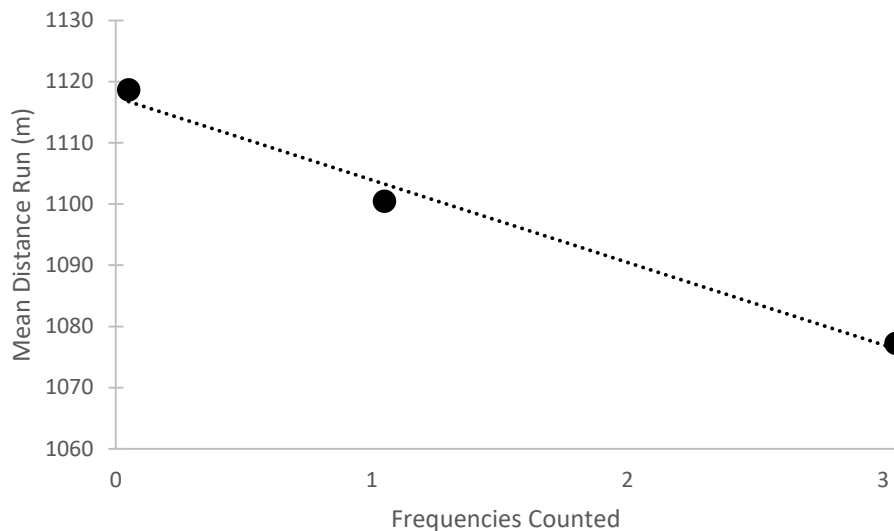


Figure 2-2: The mean distance run (m) for the three tone frequency counting conditions: 0 frequency tones counted (single-task running), 1 frequency tones counted, and 3 frequency tones counted.

As expected there was a similar decrement in tone counting accuracy to that of Blakely et al (2015); there was no significant difference in low load counting accuracy between the single and dual tasks but three-frequency counting accuracy was lower during concurrent running. This supports the research which suggests that simple cognitive tasks are not affected by physical activity as much as complex tasks.

A shorter distance was run when running was accompanied by counting indicating that counting had a detrimental effect on running performance. This appeared regardless of counting task difficulty because there was no difference was detected in running distance between concurrent low and high load counting conditions. The decrease in physical performance could be attributed to a loss of volitional control due to interference from the counting task.

Heart Rate and Physical Demand. The means and standard deviations of the heart rates for the three running conditions are presented in Table 2-2: Means (standard deviations) for distance, heart rate and subjective physical demand for run alone and dual running tasks with easy and hard counting task.

	Run Distance	Heart Rate	NASA-TLX Physical Demand
Run Alone (control)	1118.646 (39.156)	182.250 (4.149)	85.417 (4.010)
Low Load Dual	1100.450 (41.529)	181.917 (3.852)	76.250 (5.875)
High Load Dual	1077.250 (38.627)	178.083 (4.191)	77.500 (4.374)

Table 2-2: Means (standard deviations) for distance, heart rate and subjective physical demand for run alone and dual running tasks with easy and hard counting task.

We performed a repeated measures analysis of variance to check heart rates didn't differ between running condition, to ensure that it wasn't simply more effort exerted in some conditions. There were no detectable differences in heart rates between running conditions, $F(2,22) = 2.68$, $p = .091$, $\eta_p^2 = .20$. Moreover, heart rates were relatively high regardless of running condition (Table 2-2: Means (standard deviations) for distance, heart rate and subjective physical demand for run alone and dual running tasks with easy and hard counting task.). The NASA-TLX Physical Demand score means and standard errors are also displayed in Table 2.2. We performed a repeated measures analysis of variance to determine the NASA-TLX Physical Demand ratings significantly differed across the three running conditions. There was a significant difference across the running conditions, $F(2,22) = 3.98$, $p = .034$, $\eta_p^2 = .27$. Running alone was rated as significantly more physically demanding than running with either cognitive task. Nevertheless, Physical Demand ratings, like heart rates,

were relatively high regardless of running condition and may have been rated as higher in the run only condition because it was the sole focus of the task.

2.5 Discussion

Dual task performance in which a physical task and a cognitive task are performed concurrently has been studied using stationary cycles, treadmills and even rock climbing (Green & Helton, 2011; Labelle et al., 2013). Blakely et al (2015) specifically tested the effects in a real world setting combining natural terrain running, while performing a tone counting task of varying cognitive load. They found as cognitive task difficulty increases, running speed decreases, and interestingly only the hard cognitive task showed an accuracy detriment in the dual task condition, relative to the seated control session.

The current experiment expanded on the work by Blakely et al. (2015) by including additional physiological measurements, and minimising the potential peripheral visual interference by having participants respond verbally to the task instead of manual button pressing. As the cognitive task became more difficult, running speed decreased which is consistent with previous research (Blakely et al 2015). As peripheral interference was eliminated or at the minimum reduced considerably, this interference between running and tone counting is likely due to executive or central cognitive interference, not peripheral or sensory interference. Interestingly, there was no significant cognitive task interference in the low load run condition. This could be due to increased global cortical arousal resulting from physical work which may have ameliorated the interference effects to some extent (Dietrich and Audiffren 2011). Indeed, this explains why simple cognitive tasks, like reaction time tasks often improve with physical activity. The negative impact of running on cognitive task performance may be notable only when the cognitive demands of the task are high. Cognitive task performance showed a significant decline only when the high load cognitive task was

performed while running. One explanation is that the high load cognitive task and running are competing for the same resources. The counting task uses working memory which would result in activity in the prefrontal cortex and other cerebral regions (Brill et al., 2007). Given that running is interfering with working memory processes, suggests running may be competing for resources in the prefrontal cortex. Volitional control of running speed or plausibly the need to actively focus on running technique may place demands on the prefrontal cortex and other cerebral regions active during executive control. Another possibility is resourcing competition between the cortical networks necessary for tone-counting and other cortical networks necessary for motor control (Dietrich and Audiffren 2011). This issue would be resolvable in future studies employing mobile imaging technologies, such as functional near-infrared spectroscopy; mobile imaging technology is improving rapidly (Piper et al., 2014).

The VO_2 max results demonstrate that participants were of a good or above average fitness level and were all capable of completing the running task effectively. The heart rate results indicate participants were running hard in all three running tasks; they were not simply pacing themselves and deciding to work less in the dual-task conditions. Although it is possible that the stress from completing the dual task raised the HR of participants who were not running as fast as they could've been, therefore masking the fact that the physical effort was in fact less, it appears expended effort was equal between conditions. Instead they may have been unable to either will themselves to run faster or perhaps, running itself is more cognitively demanding (even on a flat track) than implicated in the literature. Even on flat terrain the person has to place their feet in the right position and to regulate their gait, posture and running form (pumping their arms, forward lean from the ankles, foot strike and lifting the leg high in follow through). Perhaps additional cognitive load interferes with the ability to

keep proper form and future studies could employ kinematic video analysis as seen in gait experiments to explore this issue.

Performance decrements from single to dual tasks have been observed in this experiment and replicated those found previously by Blakely and associates (2015). Additional cognitive load appears to be limiting to total performance, including physical output and performance. It appears that the act of willing oneself to run fast may be a plausible source of interference with increased cognitive load. Previous research does indicate that prior mental fatigue reduces subsequent physical output and performance (Marcora et al., 2009). Therefore depletion of cognitive resources may impair volitional physical output and performance. This has both theoretical implications and applications to real-world environments. Many real world occupations and settings may require a person to perform cognitive tasks concurrently with physical activity. The present and past findings suggest adding cognitive load will reduce physical output. This may be critical where the physical task is of more importance immediately. For example, a rural firefighter may need to move quickly over rough terrain from point A to point B, but may also be tasked with cognitive tasks simultaneously while using radio or in the future wearable computing technologies (Woodham et al., 2016). If the immediate need is for the firefighter to get from point A to point B as quickly as possible and the other cognitive tasks can wait, then the present research, for example, suggests eliminating the cognitive tasks would be prudent to enable the firefighter to run or move as fast as possible.

Chapter 3 – The Impact of Cognitive Load on Kayaking

3.1 Abstract

Twelve people participated in a dual-kayak cognitive counting task experiment, during which they completed five conditions, two dual tasks, two seated tasks in either low or high load and one kayak only task (control). They used their own paddling gear and were played a counting task designed to tax working memory through headphones, giving a verbal response to report the fourth tone counted of either the low tone only (low load) or all three tones simultaneously (high load). Results were similar to the running experiment, the low load counting task showed no difference to the control condition but the high load task did. Participants did however perform better in the control conditions overall than in the dual tasks. Kayak speed results were mostly as expected; as the task became more difficult, kayak speed decreased. There was a drop between control (paddle only) and the low load conditions that didn't drop much further in the high load condition. This suggests that kayak performance was affected by the addition of a complex thinking task even at low load showing kayak performance is particularly susceptible to cognitive resource interference.

3.2 Introduction

The detrimental dual task effects of coupling cognitive tasks and physical activity has been well documented (Blakely et al., 2015; Dietrich & Audiffren, 2011; Dietrich & Sparling, 2004; Epling et al., 2016; Green et al., 2014; Green & Helton, 2011). However there are still many questions remaining; results differ between tasks, intensities and types of physical activity. It is still unclear why some physical tasks show more of an effect than others but it has been noted that the level of intensity (aerobic) affects performance on the dual task (Labelle et al., 2013). Lambourne & Tomporowski, (2010) found no differences between conditions in cyclist's performance, but significant differences in runner's task performance. These comparisons were made using different cognitive tasks and physical activities and consistency of task and design would bring more clarity to results. Running (experiment two) is arguably the most aerobic sporting activity and also the most automatic and well-practiced. It is interesting to note that running dual task experiments show varying results compared with single muscle group hand grip experiments which are non-aerobic exercises (Blakely et al., 2015; Epling et al., 2016; Voelcker-Rehage & Alberts, 2007). The different aerobic, anaerobic nature of the two tasks and the cognitive complexity of the physical tasks appears to create very different results (Dietrich & Audiffren, 2011). Running is a relatively automatic task whereas kayaking requires focus on technique and balance which makes it an interesting comparison. Running exhausts the lungs, is aerobic and uses mostly the legs, whereas kayaking requires both strength and stamina; it uses core muscles, arms and legs, and requires cardiovascular as well as strength fitness (Oliveira Borges, Dascombe, Bullock, & Coutts, 2015).

Kayaking is a technical sport focusing on core strength and correct technique to reach maximum speed. There is also an element of risk, the fear of falling into the water and coming to harm on rocks pose a real threat to safety. The current experiment uses the same

cognitive counting task and design as the running experiment (Experiment two) but with kayaking.

The literature results so far state that the higher the intensity and the greater the complexity of the task, the greater the dual task performance decrement. Therefore it is expected kayaking will affect cognitive task performance more negatively than running due to the greater complexity of technique and balance (not tipping), than there is in running. It is also expected that kayak performance will show a linear trend as load increases, distance decreases.

3.3 Method

3.3.1. Participants

Participants were 12 (8 male, 4 female) experienced kayakers aged between 23 and 52 years of age (M 36.42, SD 9.95). This experiment was approved by the University of Canterbury's Human Ethics Committee and all participants were treated in accordance with the ethical guidelines. They were reimbursed for their time with a petrol voucher.

3.3.2 Materials

River Flow. River flow was measured with a Flow Probe FP101 by Global Water, (www.globalw.com) which measures the maximum and average velocities of river flow. The probe was placed 10cm deep into the water to measure the flow where the kayak will be moving through the water. The propeller of the probe is held in the water for ten seconds and then removed. The average velocity reading was taken for each kayaker. River flow made little correlational difference to paddle performance $r = -0.32$.

Wind Speed. Wind speed was measured using a Kestrel 4500 Pocket Weather Tracker by NKAU (www.kestrelweather.com). Average wind speed and temperature was measured just prior to the experiment from the starting point. This gave a true wind speed measure without the acceleration of the kayak and other variables. Wind speed made little correlational difference to paddle performance, $r = -.24$.

Avon River location and kayak equipment. The experiment took place on the Avon River, Christchurch, New Zealand. The Avon river is a popular paddling location due to its convenient location and being a body of flat water with little current and therefore ideal for speed work. The experiment used a mostly straight part of the river from the Arawa Canoe Club pontoon, to the final distance paddled in five minutes. Participants brought their own kayak, paddle, spray skirt, kayak booties, PFD (personal flotation device) and wore their own warm, comfortable clothing. Long boat kayaks were used which are mostly made from a carbon Kevlar blend, designed for endurance sport to be strong (to withstand rocks in rapids) and light (to assist with endurance speed). They have rudders to steer, controlled by foot pedals. Effective paddle technique involves rotating the core of the body and pushing off the foot plate with your legs, while focusing on the angle and placement of the paddle.

Physiological measures. Resting heart rate, PA-R height and weight were measured. These measures were used to estimate non exercise vo_2 . All participants were good or above vo_2 fitness level.

Tone counting task. The tone counting task was the same as used in the previous experiment.

NASA TLX. The NASA TLX questionnaire was the same as used in the previous experiment.

3.3.3 Procedure

Participants were presented with an information sheet and consent form upon arrival. They were informed that they would be required to complete five conditions; two dual paddling and counting tasks, one paddle only task and two seated counting tasks. They were asked to stay to the right hand side of the river but not too close to the side to collect weed on their rudder, and to follow the same line each time.

Participants were given the opportunity to warm up in their kayaks, and when they were satisfied, they took their position at the end of the pontoon touching one paddle blade to the tape marked on the pontoon. Participants had a 3-2-1 countdown for the start of the task, and the researcher started the app by pressing the start button. Participants were advised to paddle as fast as they could. Participants paddled along the side of the river for 5 minutes. The researcher followed kayakers on a mountain bike and recorded their final distance on the river bank by standing in line with the hull of the boat when the five minute count was up, and a marker was placed in the grass to measure later. Participants wore a headset and headphones and reported responses as they paddled. There were three paddling conditions, low, high and no load; there were also two seated tasks. Heart rate was recorded to ensure maximum effort was given equally to each task.

3.4 Results

3.4.1 Tone-Counting Performance

Kolmogorov-Smirnov and Shapiro-Wilk normality tests were statistically significant for not just the individual measures of tone counting accuracy, but also for the differences between the respective single and dual task conditions, $p < .05$. We, therefore, compared the single-task and dual-task conditions for each difficulty level using nonparametric tests. For

the one-frequency tone counting task (low load) there was no significant difference between the single-task (Mdn = 100.00) and the dual-task (Mdn = 87.50), $Z = 1.18$, $p = .237$, $r = .32$. For the three-frequency tone counting task (high load) there was a significant difference between the single-task (Mdn = 50.00) and the dual-task (Mdn = 25.00), $Z = 2.40$, $p = .016$, $r = .69$.

3.4.2 Kayaking Performance

Kolmogorov-Smirnov and Shapiro-Wilk normality tests were not statistically significant for the measures of kayaking distance, $p < .05$. We, therefore, compared the kayaking tasks using two orthogonal contrasts using paired t-tests. Our first test was between the kayaking single-task with the average of the kayaking tasks with the tone-counting task. Kayakers were significantly better in the single-task ($M = 846.83$, $SD = 68.97$) than in the combined kayaking with tone-counting task ($M = 826.04$, $SD = 64.61$), $t(11) = 4.18$, $p = .002$, $M_{\text{difference}} = 20.79$ 95% CI [9.85, 31.73]. There was not a significant difference between the kayaking with one-frequency tone-counting task (low load) ($M = 827.01$, $SD = 64.75$) and the kayaking with three-frequency tone-counting task (high load) ($M = 825.06$, $SD = 65.31$), $t(11) = .456$, $p = .657$, $M_{\text{difference}} = 1.95$ 95% CI [-7.47, 11.37].

For descriptive purposes we also examined the decrease in distance paddled with increasing number of frequencies counted (zero frequencies counted, one frequency and three frequencies counted). As with the previous experiment the slope of the line of best fit was determined for each subject and these slopes averaged, $M = -6.36\text{m}$, $SD = 7.82$, 95% CI [-11.06; -2.67]. The average line of best fit is displayed in Figure 3-1: The mean distance (m) kayaked for the three tone frequency counting conditions: 0 frequency tones counted (single maths-task), 1 frequency tones counted, and 3 frequency tones counted.3.1.

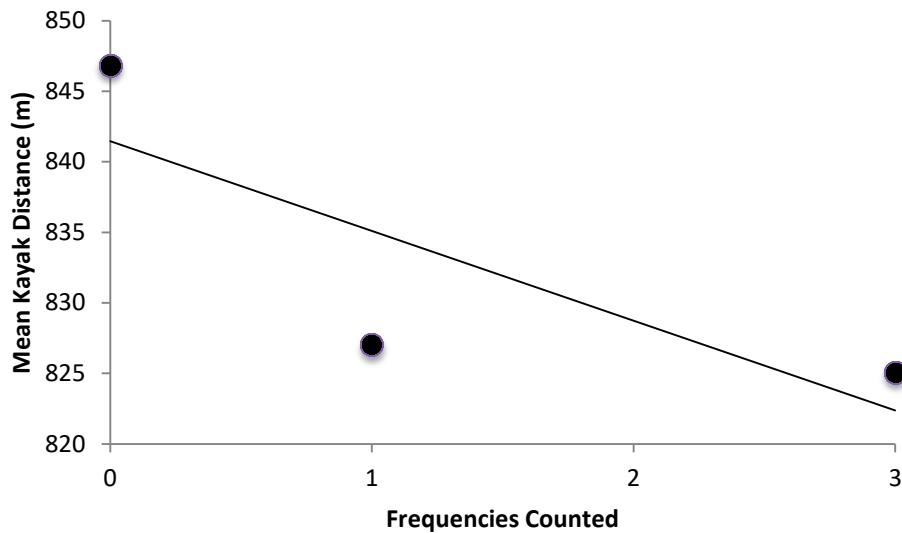


Figure 3-1: The mean distance (m) kayaked for the three tone frequency counting conditions: 0 frequency tones counted (single maths-task), 1 frequency tones counted, and 3 frequency tones counted.

3.4.3 NASA TLX – Tension

The NASA TLX tension scale was used to analyse if the kayak task was creating more tension in the kayakers than the seated task. Averages were taken from the seated and kayak tasks and were then compared. Participants reported more tension in the kayak dual task ($M=47.30$, $SD=23.04$), than in the seated tasks ($M=28.33$, $SD=23.04$), $t(11) = 4.41$, $p = .001$, $M_{\text{difference}} = 18.96$, 95% CI [9.49, 28.43].

3.5 Discussion

Tone counting accuracy while paddling show similar results to that of running; there was no significant difference between the dual low load and the seated low load, again suggesting there is a level of cortical arousal that assists performance. However, there was a

significant difference between the dual high load and the seated high load stating again that when a hard cognitive task is coupled with high intensity physical activity the cognitive task is not completed correctly due to interference.

There was a significant difference in the distance travelled between kayaking with no task and the average of the kayak dual tasks. This suggests that the task was interfering with physical performance. There was, however, no significant difference between the low load distance and the high load distance. Again, these results are similar to the running experiment; however, figure 3.1 clearly shows there is a sharp decline in distance between the no load and low load, and the low load and high load seem to remain similarly slower (less distance). It is possible that participants reached maximum interference in the low load condition and it therefore could not decline any further in the high load condition.

The next step comparison must use the same dual-task paradigm with an anaerobic sport that focuses on strength less than cardiovascular fitness. Kayaking speed appears to be more effected than running speed in the low load task condition and it would be interesting to see if a completely different sport follows this trend.

Chapter 4 - The Impact of Cognitive load on Rock Climbing

4.1 Abstract

Rock climbing is a particularly cognitively demanding sport. Planning, movement, reaching, posture control, and fear of falling have all been evidenced to use cognitive attention (Bourdin, Teasdale, & Nougier, 1998; Green et al., 2014; Green & Helton, 2011; Teasdale, Bard, Larue, & Fleury, 1993). For these reasons it was chosen to compare with previous dual running and kayaking experiments that used a counting task as the dual task (Blakely et al., 2015). Using an identical dual task experiment design as previous experiments (chapters two and three), rock climbers completed five conditions, two dual, two single and one climb only. The results showed a difference between the single and dual tasks in the low and high load conditions for counting accuracy. Rock climbing task performance was no different in the single task compared to the combined dual tasks, but there was a difference between the high and low load conditions. This interesting result suggests that the physical task was mentally prioritised over the cognitive task (contrary to the other experiments).

4.2 Introduction

Our goals for this experiment were to examine the dual task effect of the tone counting (working memory) task on rock climbing performance. Climbing can be construed as a mentally demanding activity due to movement planning, postural control and fear of falling (Alexander Louis Green & Helton Nick Draper, 2012; Green et al., 2014; Green & Helton, 2011).

There are attentional demands required to execute movement; when one is static in rock climbing, they have their weight on their legs and use their arms to balance, and when in movement the postural control has to shift to accommodate only three points of contact on the surface (Bourdin et al., 1998; Darling & Helton, 2014; Woodham et al., 2016). Movement while climbing itself demands attention but reaching movements and postural control also uses attention resources (Bourdin et al., 1998; Teasdale et al., 1993). Taking these two factors into account along with decision making about where to climb, it's easy to see how rock climbing is a cognitively demanding activity.

Another factor to consider is the emotional fear of falling. Dual task experiments using walking and the elderly show that fear of falling increases under dual task conditions (Wollesen, 2016). Not only this but various gait changes can be observed when participants walk in a dual task condition (Wollesen, 2016). It seems reasonable then to assume that the fear of falling will be an additional interference factor in a rock climbing dual task experiment where the fall could result in serious injury or death in real life settings. Even when settings prevent harm with crash mats and safety harnesses it is reasonable to suggest that fear of falling is an innate adaptive response to prevent harm. If this is the case we would expect to see a prioritisation of the climbing task over the cognitive task, but still see the tasks performed worse as the cognitive load increases.

4.3 Method

4.3.1 Participants

Participants were 12 (10 men, 2 woman) rock climbers. The mean age of participants was 24 years (SD 4.63 years). Participants were required to have a climbing fitness level enabling them to traverse the climbing wall for five minutes. This experiment was approved by the University of Canterbury's Human Ethics Committee and all participants were treated in accordance with the ethical guidelines. Participants received a shopping voucher as compensation for their time.

4.3.2 Materials

Climbing wall. The experiment took place at the University of Canterbury Recreation Centre, on the indoor rock climbing wall. The experiment used 8.25m of climbing wall and the height was restricted by a red tape at 3.3m, given the participants were not harnessed. The floor of the climbing wall was cushioned to prevent injury. Participants brought their own climbing shoes and wore clothing they were comfortable climbing in.

Tone counting task. Tone counting task administration was the same as employed in the previous experiment.

NASA TLX. The NASA TLX questionnaire was the same as employed in the previous experiment.

4.3.3 Procedure

Upon arriving at the climbing wall participants were presented with an information sheet and consent form. They were informed that they would be required to complete five conditions; two dual climbing and counting tasks, one climbing only task and two seated counting tasks.

Participants were given the opportunity to warm up on the climbing wall, and when they were satisfied, they took their position on the far left of the climbing wall with one leg and one arm touching the adjoining wall. Participants wore a small back pack to hold the cell phone while they climbed. The experiment began with a 3-2-1 countdown by the researcher who started the cell phone counting app and dropped it into the front pocket of the back pack. Participants were advised they could use any holds they pleased, up to the 3.3m mark on the wall which indicated the safe free climbing height. Participants traversed across the wall until they reached the corner and touched a hand and foot on the adjoining wall, at which time; they went back in the other direction. This process was then repeated as many times as they could continuously for five minutes. If the participant came off the wall, they were advised to get back on at the same point they came off and continue with the climb. During the climb the participants were played the tones for the counting task. There were three climbing conditions, low load counting task where they counted the low tone only, high load counting task where they counted all three tones simultaneously and a climbing only task where the tones were played but counting was not required. There were also two seated tasks completed; a low load seated task where participants counted only the low tone, and a high load seated task where they counted all three simultaneously.

Seated counting task. For each of the two seated counting tasks, participants were seated on the mat of the rock climbing room. They were instructed to count every fourth tone of just the low tone (low load) or all three tones (high load) for five minutes and respond using “high, mid or low” for the corresponding fourth tone. The participant initiated the start of each task using the start button.

Dual tasks. The two dual task conditions combined rock climbing and the counting task. Participants received the same instructions for the tone counting task as in the seated trials. Self-reported recovery time was used to indicate the start of the next condition (heart rate was required to be at or below 100bpm) before proceeding to the next test.

Participants were instructed to climb as fast as they could and were not asked to prioritise either task. Upon completion of each condition the participants were given the NASA TLX questionnaire. All participants completed the tasks in a different order using a Latin square design to avoid practice and fatigue effects.

4.4 Results

4.4.1 Tone-Counting Performance

Kolmogorov-Smirnov and Shapiro-Wilk normality tests were statistically significant for not just the individual measures of tone counting accuracy, but also for the differences between the respective single and dual task conditions, $p < .05$. We, therefore, compared the single-task and dual-task conditions for each difficulty level using nonparametric tests. For the one-frequency tone counting task (low load) participants performed significantly better in the single-task (Mdn = 100.00) than in the dual-task (Mdn = 68.75), $Z = 2.98$, $p = .003$, $r =$

.86. For the three-frequency tone counting task (high load) again, performance was significantly better in the single-task ($Mdn = 100$) than in the dual-task ($Mdn = 37.5$), $Z = 2.54$, $p = .011$, $r = .73$.

4.4.2 Climbing Performance

Kolmogorov-Smirnov and Shapiro-Wilk normality tests were not statistically significant for not just the individual measures of tone counting accuracy, but also for the differences between the respective single and dual task conditions, $p < .05$. We, therefore, compared the climbing tasks using two orthogonal contrasts, using paired t-tests. Our first test was between the climbing single-task with the average of the climbing tasks with the tone-counting task. Climbing with the single-task ($M = 634.64$, $SD = 238$) was not significantly different to climbing with the combined climbing with tone-counting task (dual task) ($M = 610.74$, $SD = 220.68$), $t(11) = .66$, $p = .521$, $M_{\text{difference}} = 358$, 95% CI [55.47, 103.28]. Climbers did however climb significantly faster in the one-frequency tone-counting task ($M = 626.11$, $SD = 213.70$) compared to the three-frequency tone-counting task (dual task) ($M = 595.36$, $SD = 229.82$), $t(11) = 2.28$, $p = .043$, $M_{\text{difference}} = 30.75$ 95% CI 1.11, 60.38].

For descriptive purposes we also examined the decrease in climbing distance with increasing number of frequencies counted (zero frequencies counted, one frequency and three frequency tasks). As with experiment one we found the slope of the line of best fit for each subject and then averaged these slopes across subjects, $M = -1.34$, $SD = 3.77$, 95% CI [-3.42; .62]. The average line of best fit is displayed in Figure 4-1: The mean distance climbed for the three tone frequency counting conditions: 0 frequency tones counted (single climbing task), 1 frequency tones counted, and 3 frequency tones counted.

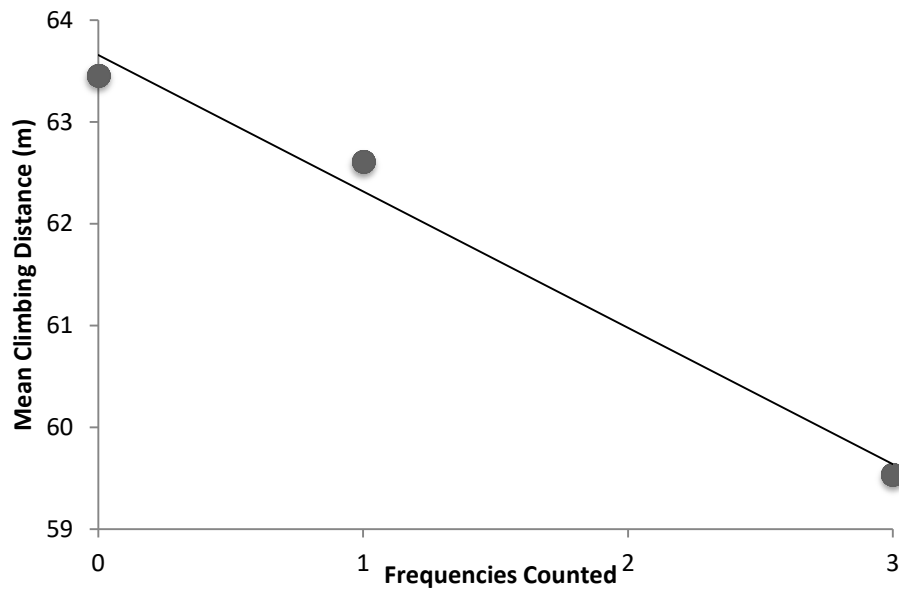


Figure 4-1: The mean distance climbed for the three tone frequency counting conditions: 0 frequency tones counted (single climbing task), 1 frequency tones counted, and 3 frequency tones counted.

4.4.3 NASA TLX – Tension

Due to the apparent preference to the physical task in this experiment, the NASA TLX tension scale was used to analyse if the climbing task was creating more tension in the climbers than the seated task. Averages were taken from the seated and climbing tasks and were then compared. Participants reported more tension in the climbing task ($M=28.72$, $SD=20.64$), than in the seated tasks ($M=16.54$, $SD=15.66$), $t(12) = -3.41$, $p = .005$, $M_{\text{difference}} = -12.18$, 95% CI $[-19.96, -4.4]$.

4.5 Discussion

Counting accuracy was better in the seated conditions when compared with the dual task conditions for both the low and high load conditions for counting performance. This

suggests that climbing is having more of a detrimental effect on the ability to attend to the tone counting task. It suggests that climbers are more focused on the physical task at hand, which may be due to the overwhelming attentional demands of climbing, and therefore not concentrating on the cognitive task.

There wasn't a significant difference in climbing distance between the climb without a task and the average dual task climb conditions; however there was a significant difference between the low load and high load. Climbing distance therefore was not effected by doing a task or not, again suggesting attention was focused on climbing and less on the cognitive task.

There was a significant difference between the low and high load distances meaning the high load task did affect climbing speed more than the low load. This suggests that although participant attention was mostly on the climbing task at least some of participant attention was also on the counting task, which did have an effect on their climbing speed as it became more difficult.

There are many attentional demands in rock climbing, planning, movement, reaching, posture and fear of falling (Bourdin et al., 1998). There are certainly elements of planning, movement and posture in running; and there is all of these and a fear of falling into the water in kayaking, especially in tippy boats. Considering the climbing mat was thick and padded there should've been no more fear of falling causing physical damage in the climbing condition than in the kayak. Hearing fear-related words significantly decreased climbing speed and movement times indicating the impact this emotion can have on rock climbing (Green et al., 2014; Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008). It may be that rock climbing is tapping into an innate fear of falling that is not 'overridden' by our logic thought process; even when a climber knows there is little risk of harm, there may still be anxiety

about falling. This would also be consistent with the significant difference in ratings of tension between the climbing condition and the seated condition.

Chapter 5 – The Impact of Cognitive Load on an Arithmetic Task

5.1 Abstract

A simple maths equation task was developed as a comparative measure to the physical activity tasks and was designed to investigate interference to the tone counting task and as a seated control to the physical tasks. Participants completed the tone counting task at the same time as a basic arithmetic task on a computer for the dual task conditions. They were required to complete addition or subtraction up to ten, and only correct responses were counted. Performance accuracy on the counting task was worse when comparing the single and combined dual tasks, and worse in the high load than the low load. Participants completed less maths addition and subtraction equations (comparison to the physical tasks) in the single than the dual condition and in the high load compared with the low load conditions. This was the same as the running and kayak experiments (chapters 2 & 3) and to be expected. The addition and subtraction tasks as well as the counting task is an example of the most overlap two tasks share in resource availability according to multiple resource theory.

5.2 Introduction

Dual task experiments are frequently used to report the effects of limited resources in physical and cognitive tasks. Detrimental effects can be observed in dual cognitive task experiments (Helton et al., 2010; Helton & Russell, 2011; Wilson, Russell, & Blakely, 2005). According to Wickens multiple resource theory (MRT) different concurrent activities affect the available cortical resources, and subsequent performance outcomes in different ways (Wickens, 2008). The stages (working memory) and codes (spatial vs verbal) of processing, modalities (senses), and visual processing (focal or ambient) can be observed in all dual task settings and the more similar two tasks are, the greater the conflict and subsequent loss of performance. Observing the experiments in chapters two, three and four we can see that different physical tasks create different resource utilisation and conflict with the working memory task created for these experiments. In order to understand the cognitive complexities of these physical activities and specifically how they create interference, it is necessary to understand the effect of the counting task (working memory) on a task that is very similar to itself, another maths task.

Evidence suggests that simple arithmetic constitutes an interfering task in a dual task setting (Raghubar, Barnes, & Hecht, 2010). The previous experiments (chapters two, three and four) were experiments with a dual physical task, however to understand the true impact physical activity has on the dual task paradigm it should be tested with a seated maths task which creates the most overlap of resources. The maths task (which was designed to be the seated equivalent of distance in the physical tasks) had participants answer simple maths equations up to and including 10. The equations contained two numbers and plus or minus (e.g. $4+7$) and answers were positive or negative. After the practice phase participants were instructed to answer as many equations as possible. Using the same design as the previous experiments, every participant completed three maths (two dual) and two counting

only tasks of low and high load. This served as a comparison to the physical tasks, and was used to establish if there was a difference between the maths and physical tasks when combined with the dual counting task.

We expect both tasks to show more decline in correct responses in the dual task compared with single task conditions, and when the difficulty increases from low load to high load. We expect the results to follow a similar trend to first two experiments, with a more pronounced decline in accuracy of the counting task and less arithmetic questions completed considering the similarity of the two tasks and subsequent resource overlap.

5.3 Method

5.3.1 Participants

Participants were 12 (3 males, 9 females) volunteers aged between 20 and 38 (mean 30.08, SD 6.37). This experiment was approved by the University of Canterbury's Human Ethics Committee and all participants were treated in accordance with the ethical guidelines. They were reimbursed for their time with a shopping voucher. The experiment was conducted at the Human Factors Laboratory at the University of Canterbury.

5.3.2 Materials

Tone counting task. The tone counting task was the same as employed in the previous experiment.

NASA TLX. The NASA TLX questionnaire was the same as employed in the previous experiment.

Maths equations task. Participants viewed basic addition and subtraction questions using digits from 1-10 for five minutes. They responded by typing in the response number and pressing the enter key. They were advised the answers could be a negative number, in which case they had to type the negative symbol. A practice session with five questions was given with 'correct' or 'incorrect' responses. The experiment was started by the participant and the experiment conditions did not indicate if responses to maths equations were correct or not.

5.3.3 Procedure

Participants were given information, consent forms and experiment instructions while seated at a computer. Participants sat at individual computer workstations approximately 50cm from eye-level screens (377 x 303 mm, 60 Hz refresh rate) and navigated through practice equations at their own pace. The tone counting task was played through sound attenuating headphones which also had a mic for verbal responses; participants were shown how to adjust the tones to a comfortable level, as well as being given a practice tone counting task. All questions were answered at this time. The experiment followed the same protocol as previous, with a total of five conditions, two dual, two counting alone and one maths equations alone, with order effects attenuated by a Latin square design.

5.4 Results

5.4.1 Tone-Counting Performance

Kolmogorov-Smirnov and Shapiro-Wilk normality tests were statistically significant for not just the individual measures of tone counting accuracy, but also for the differences between the respective single and dual task conditions, $p < .05$. We, therefore, compared the single-task and dual-task conditions for each difficulty level using nonparametric tests. For the one-frequency tone counting task (low load) there was a significant difference between the single-task (Mdn = 100.00) and the dual-task (Mdn = 87.50), $Z = 2.714$, $p = .007$, $r = .78$. For the three-frequency tone counting task there was also a significant difference between the single-task (Mdn = 68.75) and the dual-task (Mdn = 37.50), $Z = 2.88$, $p = .004$, $r = .83$.

5.4.2 Maths Task Performance

Kolmogorov-Smirnov and Shapiro-Wilk normality tests were not statistically significant for the measures of maths equations correct, $p < .05$. We, therefore, compared the maths tasks using two orthogonal contrasts using paired t-tests. Our first test was between the maths single-task with the average of the maths tasks with the tone-counting task. There was a significant difference between the maths single-task ($M = 168.25$, $SD = 34.40$) and the combined maths with tone-counting task ($M = 115.04$, $SD = 33.64$), $t(11) = 7.53$, $p = .000$, $M_{\text{difference}} = 53.21$ 95% CI [37.66, 68.76]. There was a significant difference between the maths task with one-frequency tone-counting task ($M = 133.50$, $SD = 34.44$) and the maths task with three-frequency tone-counting task ($M = 96.58$, $SD = 35.86$), $t(11) = 6.27$, $p = .000$, $M_{\text{difference}} = 36.92$ 95% CI [23.96, 49.87].

For descriptive purposes we also examined the decrease in number of math problems completed with increasing number of frequencies counted (zero frequencies counted, one frequency and three frequencies). This was examined by computing the slope of the line of best fit for each subject and finding the mean slope over all subjects, $M = -23.11$, $SD = 8.06$, 95% CI $[-27.79; -18.96]$. The average line of best fit is displayed in Figure 5-1: The mean number of maths tasks completed for the three tone frequency counting conditions: 0 frequency tones counted (single maths-task), 1 frequency tones counted, and 3 frequency tones counted.

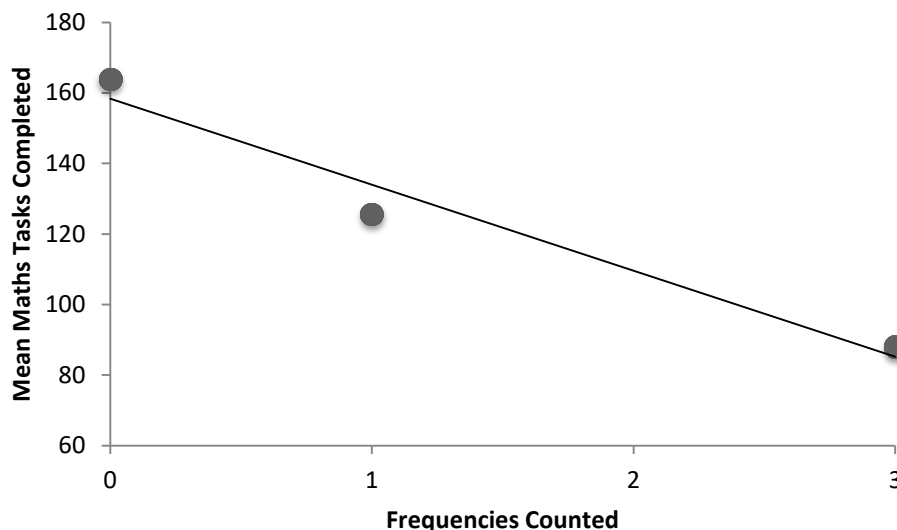


Figure 5-1: The mean number of maths tasks completed for the three tone frequency counting conditions: 0 frequency tones counted (single maths-task), 1 frequency tones counted, and 3 frequency tones counted.

5.4.3 NASA TLX – Tension

Due to the results of the rock climbing experiment (chapter 4) we needed a comparison tension metric. This was to establish if anxiety was the source of cognitive

interference between the dual and single tasks in climbing. Averages were taken from the single and dual tasks for each participant and were then compared. Participants reported more tension in the dual task ($M=63.75$, $SD=27.25$), than in the single task ($M=47.08$, $SD=29.69$), $t(11) = -2.65$, $p = .023$, $M_{\text{difference}} = -16.66$, 95% CI $[-30.52, -2.81]$.

5.5 Discussion

As expected participants were more accurate in the single task than the dual task condition for both the low and high load conditions, suggesting the dual task had a detrimental effect on tone counting task accuracy.

The number of equations solved correctly was significantly better in the equation only condition when compared with the average dual task conditions, again demonstrating dual-task interference costs. There were fewer equations solved in the high load condition than in the low load condition; as the counting task became more difficult, creating more interference, the number of equations solved decreased as a consequence. These results indicate there is a significant conflict in attentional resources that affect both the tone counting and number of correct equations completed as predicted in our hypothesis.

Interestingly, participants were tenser in the dual task conditions when compared with the single task conditions. This was similar to the rock climbing experiment (chapter 4) and shows that, regardless of physical task complexity or perceived fear of falling in rock climbing, participants found the dual task more stressful than the single. This may mean a further explanation is required for the rock climbing results.

Chapter 6 – Comparative Analysis of the Running, Kayak, Rock Climbing and Arithmetic Experiments

6.1 Introduction

Results show that counting task accuracy was significantly less in the high load condition for all activities, but only significantly less in the climbing and maths task in the low load counting task condition when compared with the single task. This result is expected for the maths equation task because the task was designed to create the most amount of overlap according to MRT, however it is interesting to note that rock climbing made participants less accurate in the counting task for both the low and high load when compared with the single task. This means they could not perform the rock climbing task at all without it creating interference with the counting task. Therefore, the results suggest that different activities affect the counting task accuracy in different ways.

While it is interesting to view the results together, it is not technically accurate to compare distance figures because they measure different activities, and need to be standardised first in order to compare the relative differences.

6.2 Comparative Impact on Tone Counting

In order to compare the impact of the four tasks on tone-counting performance we calculated the average difference between single-task (low load), when there was no other task demand, and dual-task tone counting. We did this by averaging the differences between the single and dual tasks for both the one frequency (low load) and the three frequency tone (high load) counting tasks. We then employed orthogonal contrasts to test first for significant differences between climbing and the other three tasks, then to test for significance differences between the math-problem-solving task and the two cyclic tasks (running and

kayaking), and then finally to test for significant differences between running and kayaking. There was a significant difference between climbing and the other conditions, $p = .025$, $M_{\text{difference}} = 15.625$ 95% CI [2.027, 29.223], but there was no significant difference between math-problem solving and the two cyclic tasks, $p = .387$, $M_{\text{difference}} = 6.25$ 95% CI [-8.173, 20.673] or between kayaking and running, $p = .707$, $M_{\text{difference}} = -3.125$ 95% CI [-19.779, 13.529]. The average differences are displayed in Figure 6-1.

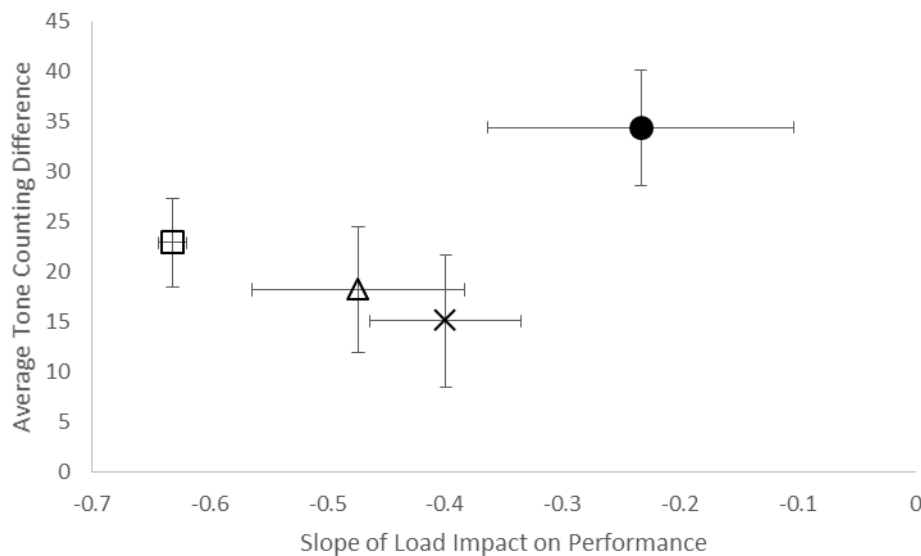


Figure 6-2: The solid black circle is climbing, the empty black box is math, the empty triangle is running and the X is kayaking.

6.3 Comparative Impact on Task Performance

Since the metrics of performance for the four tasks were not directly comparable, we transformed performance for the single-task, with one frequency tone-counting task and task with three frequency tone counting task into z-scores for each participant. Since we expected performance to, if anything, decline with increasing cognitive load we then fit a line of best

fit for each individual for 0 (single-task), 1, and 3 frequency tone counting. The average lines of best fit for the four tasks are displayed in Figure 6-2. The resulting individual slopes were then compared for the four tasks using orthogonal contrasts to test first for significant differences between climbing and the other three tasks, then second to test for significance differences between the math-problem-solving task and the two cyclic tasks (running and kayaking), and then finally to test for significant differences between running and kayaking. There was a significant difference between climbing and the other conditions, $p = .010$, $M_{\text{difference}} = .268$ 95% CI [.069, .467], but there was no significant difference between math-problem solving and the two cyclic tasks, $p = .069$, $M_{\text{difference}} = -.195$ 95% CI [-.406, .016] or between kayaking and running, $p = .543$, $M_{\text{difference}} = .074$ 95% CI [-.170; .318]. The average differences are displayed in Figure 6-2.

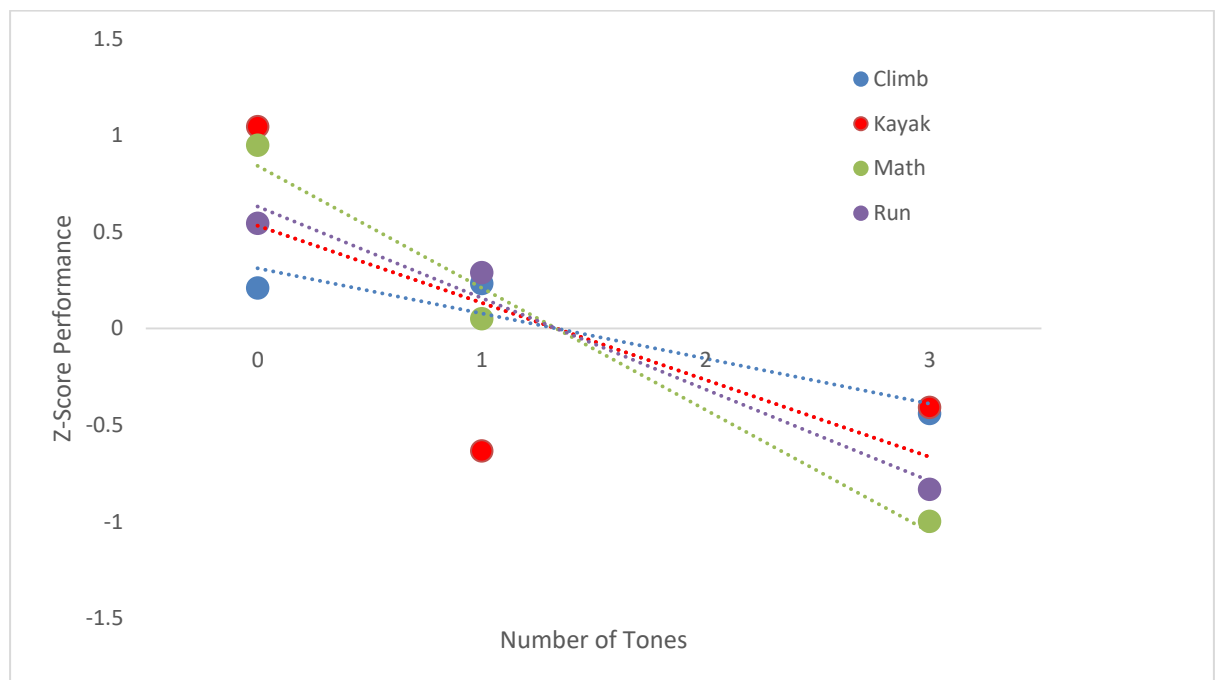


Figure 6-3: The average lines of best fit for the four tasks

6.3 Comparative Analysis Discussion

When comparing the impact of tone-counting on task performance the least impact was for climbing, however when comparing the impact of task performance on tone counting, climbing had the largest impact on tone counting performance (**Error! Reference source not found.**Figure 6-1 & Figure 6-2). Although no guidance was provided to the participants on which task should receive greater emphasis or effort in any of the experiments, this noted performance difference is indicative of a trade-off. This finding may be due to an automatic focus to maintain climbing performance due to the risks of injury while climbing. Unlike running on a flat track, climbing a traverse may not rely on automated movement programs, but may require careful planning and focused attention (Bourdin et al., 1998). In previous research using semantic memory tasks, climbing was found to have greater influence on memory than other tasks, including flat track running (Blakely et al., 2015; Darling & Helton, 2014; Epling et al., 2016; Green et al., 2014; Green & Helton, 2011; Wilson et al., 2005). This is likely due to rock climbing being one of the most cognitively demanding individual sports.

There are many cognitive aspects to rock climbing, reach speed, movement planning, postural control and fear of falling. Executing a reaching movement almost doubles the attention demand of posture control (Bourdin et al., 1998) Furthermore, experiments have shown that the programming phase (the initial thought before the movement) is the most demanding for reach attention (Bourdin et al., 1998) Reach speed is effected by the difficulty of the hold, and the speed at which the hand takes the body weight depends on how easy the hold is, an easy hold 21% body weight compared with a hard hold 14% (Bourdin et al.,

1998). As outlined here, there are several tasks demanding attention in the reach phase alone, but there are many more aspects that could potentially require cognitive input.

There is evidence stating that even holding a quadrupedal posture on a climbing wall requires a significant amount of attention compared with upright standing and static climbing (Bourdin et al., 1998; Kerr, Condon, & McDonald, 1985; Teasdale et al., 1993). Considering time taken for reaching is effected by postural instability, when participants are in a complex postural state they take more time to plan the next movement so they spend less time in a tripodal posture (Bourdin et al., 1998) This has implications in a speed task where efficiency is paramount; if posture control is receiving insufficient resource it is possible that participants will take longer planning the next hold in order to avoid an imbalanced posture. In short, in this dual task high time pressure task the shared attentional demands are in effect slowing the process.

Another possible reason rock climbing is prioritised so greatly over other tasks could be the fear of falling. Emotion has an effect on motor control (Chen & Bargh, 1999; Green et al., 2014). Negative emotion can have a strong effect on physical outcomes, specifically it has been found in previous rock climbing research that anxiety produces slower more cautious movements (Green et al., 2014; Nieuwenhuys et al., 2008; J. R. (Rob) Pijpers, Oudejans, Bakker, & Beek, 2006; J. R. Pijpers, Oudejans, & Bakker, 2005). Fear of falling in a completely safe environment generates similar experimental results to experiments with fear of falling when there is an actual danger of falling, suggesting this mechanism is innate and not consciously controlled (Green et al., 2014). There is some difficulty however, applying this theory to the current experiments due to the NASA- TLX results for tension. The climbing experiment showed participants were statistically significantly tenser when climbing when compared with seated tasks. However, the maths equation task experiment got the same results, suggesting that completing a dual task creates tension in participants. It is

not necessarily that fear of falling is creating the pronounced effects in the climbing tasks, but rather our lack of demonstrating the exclusive nature of fear in climbing when compared to the other tasks. Taken collectively with the other cognitive attention factors, anxiety of falling when time pressure is applied, may lead participants to be overwhelmed and incapable of focusing on trivial tasks like tone counting.

Indeed taken collectively these experiments show an interesting pattern of cognitive, physical task interactions. Both physical and cognitive tasks are affected when performed concurrently and there is clearly a fascinating interaction between executive cognition and physical tasks. It is reasonable to suggest that physical performance should not be analysed in isolation to cognitive functions especially in cases of dual tasks and furthermore fatigue states.

Chapter 7 – The Effects of Mental Fatigue on the Risk Perception of Cycle-ways

7.1 Abstract

The interaction between cognitive tasks and physical activity is producing interesting insight about our mental and physical performance limitations. Some research has also shown that as time goes on, cognitive and physical performance decreases, potentially due to a decline in pre frontal cortex (PFC) blood flow and oxygenation (Liu et al., 2010; Mehta & Parasuraman, 2013). This phenomena, commonly known as cognitive fatigue has implications for physical performance because the decline in cognitive resources means less attention resource is available for things like volitional control. When the PFC is fatigued it may also alter decision making, specifically risk perception (Breakwell, 2014). Due to reduced resources it is possible that we adopt conservative approaches to risk so we don't come to harm. Therefore cognitive fatigue may directly impact risk perception. To test this theory, participants were divided into one of two groups, cognitive fatigue or control, and completed 20 minutes of either a dual vigilance task or nothing at all. Upon completion they rated pictures of cycle-ways for their riskiness. The cognitive fatigue group rated the pictures as more risky than the control group which indicates a relationship between fatigue and risk. MRT states that as resources are depleted, processing efficiency of other processes decreases, in this case as resources deplete feelings of fatigue and perception of risk increases.

7.2 Introduction

The interaction between executive cognitive function and physical tasks is still unresolved and many questions about performance of these tasks remain. Chapters 2, 3, 4 and 5 addressed the dual task role of cognition and physical activity. There are certainly interesting ramifications for performance in both cognitive and physical tasks, and there are many different executive cognitive tasks that can be affected by physical tasks and vice versa. Risk perception is an example of a cognitive function that may effect and be affected by physical activity and physical or mental fatigue. From as early as 1891 Mosso wrote about mental fatigue effecting his later physical performance. He shared this phenomenon with his fellow professor's; after a hard day writing, he felt more physically fatigued also, even though he had not greatly exerted himself physically (Mosso, 1904).

Mental fatigue is defined in many ways; it has been described as a psychobiological state caused by long periods of cognitive work coupled with subjective feelings of feeling tired (Marcora et al., 2009). It has also been observed in experiments using functional near infra red spectroscopy (fNIRS) and EEG to measure oxygenation and blood flow in the PFC. These experiments have shown that as time on a physical task increases, so does PFC de-oxygenation (Liu et al., 2010; Mehta & Parasuraman, 2013). Interference in the prefrontal cortex (PFC) may influence physical fatigue development during tasks that are associated with high cognitive demands (Mehta & Parasuraman, 2013). Indeed, as muscular fatigue sets in, top down commands maintain performance through volitional control, and when cognitive resources are depleted, actions slow or stop (Mehta & Parasuraman, 2013). There is consensus that perceived muscular fatigue is at least partially due to a critical reduction in PFC oxygenation (Mehta & Parasuraman, 2013).

Marcora and colleagues reported mental fatigue as a psychobiological state caused by long periods of mental work (Marcora et al., 2009). After a 90 minute cognitively fatiguing task, participants' time to fatigue on a stationary bike reduced; they were tired faster than a control group (no cognitive fatigue) (Marcora et al., 2009). Marcora et al (2015) also found that mental fatigue reduced performance and increased perception of effort progressively during a period of intermittent running. They conclude that the perception of effort is the mediating factor, in other words when participants felt tired performance decreased, suggesting that it is the generation of cognitive fatigue that lead to the consequent impairment in performance (Smith et al., 2015). Kempton and colleagues (2008) used time motion cameras to monitor performance in rugby league players and found that as time increased the physical endurance and performance as well as the technical skill decreased (Kempton et al., 2013). This dual endurance and technical performance decrease certainly indicates how much physical activity and cognitive fatigue are linked. Not only is there obviously muscular fatigue which slows performance and decreases technical skills, but research findings suggest possibly technical skills, volitional control and performance decrease due to mental fatigue (Mehta & Parasuraman, 2013). Certainly mental fatigue appears to affect consequent physical performance however the underlying reasons for this are still not clear. It may be that as fatigue sets in the brain enters a conservative mode where it prioritises essential processing as a means to preserve resources. Intuitively if we follow the premise of MRT, other executive cognitive functions should become more conservative also.

From an evolutionary perspective as one's ability to perform physically and mentally decreases, it makes sense to adopt a mentally conservative approach, "if I jump that gap I will make it" as opposed to "I'm tired and might not make that jump". This suggests that perception of risk is a function that has evolved in order to keep us safe when our physical and cognitive resources have been depleted. Risk perception is not fully understood, and

encompasses multi-dimensional factors and several different definitions about what constitutes something being risky or not and what makes a good decision or not (Kahneman & Lovallo, 1993; Sjöberg, 2000; Slovic et al., 2005; Tversky & Kahneman, 1986). Contrary to this however, is evidence in drivers that shows fatigue instead increases risky behaviours (Paterson et al., 2016). Fatigue from sleep deprived drivers shows that they are more likely to drive when it is risky or at an unsafe limit. This is however a different type of fatigue than that induced in the vigilance tasks referred to earlier, which involve cognitive work load. (Paterson et al., 2016). Rosenbloom and colleagues (2011) found no difference in pedestrians assessment of risk while crossing a road, whether they were fatigued or not, (fatigue was not manipulated in experimental form, but rather was measured through a subjective questionnaire). Again this appears to show a contradictory finding to risk perception experiments stated earlier, there are however many differences between studies and so it is hard to compare them. Risk perception is certainly complicated and encompasses many types of risk, driving a car, smoking, the risk of nuclear war all involve quite different cognitive processes, but in situ risk during physical tasks is the focus of this research. .

Indeed there is a complicated relationship between fatigue and risk perception, defining both mental and physical fatigue, and risk perception is problematic in itself. It is however plausible that risk perception is one of the cognitive functions responsible for declined physical performance. As cognitive fatigue increases a conservative approach is increasingly adopted. To test this theory we randomly assign half a participant group to a mentally fatigued condition and the other half to a control condition with no mental fatigue. The tasks are vigilance tasks, a tracking task coupled with a dynamic sound monitoring task(jungle sounds with a target growl), which was used because it is dynamic in nature and no passive perceptual learning could take place(Head & Helton, 2015). This is in stark contrast to the control group who were completely passive for the duration of the experiment,

therefore eliciting the most and least cognitive fatigue in a seated task. Afterwards all participants will rate pictures of cycle-ways for their riskiness using three assigned questions. We expect the cognitive fatigue group to rate the pictures as more risky than the control group. Although this experiment does not have participants physically cycle the path or roadway it is designed to assess their willingness to participant in a potentially hazardous cycling environment.

Method

7.3.1 Participants

Fifty nine students (21 male) from the University of Canterbury participated as part of a class activity. Ages ranged from 19 to 38 yrs ($M = 23$ $SD = 7.2$).

7.3.2 Materials

Tracking task. A neon-green cursor and red bulls-eye were presented on a black background. The cursor comprised a cross consisting of four equilateral appendages (7 mm \times 7 mm, 3 mm width). The cursor moved by itself at random on the horizontal plane. Cursor movement was restricted so it could only travel 130 mm to the left or right of the centre of the bulls-eye. The frequency and amplitude of the cursor movement were determined by using three separate sine functions that created the appearance of random movement. The bulls-eye was a solid red circle with a diameter of 6 mm, and was enclosed by a 15-mm-diameter red ring that was 1.5 mm in width. Participants were instructed to keep the moving cursor in the centre of the bulls-eye as best they could. Cursor movement was controlled by

the computer mouse. Presentations (both audio and visual) and recordings of tracking accuracy and questionnaires were executed on PC computers using E-Prime Professional 2.0 (Head & Helton, 2015).

Lion growl task. Participants were asked to respond to an auditory target presented randomly to their left or right ear. The auditory target was a clip of a male lion growling. The lion growl auditory target was that used by (Head & Helton, 2015) and was created by taking a single 3400 ms auditory clip of a lion growling and editing into four separate 850 ms sound bites (Head & Helton, 2015). This was obtained from <http://www.soundjax.com/?g=Lion+growl>. A 20-min jungle sounds clip was used as a background auditory mask while participants monitored for the lion growl target (Head & Helton, 2015). The auditory target (lion growl) and mask (jungle sounds background) were presented to participants using RP-HT161E-K headphones at a comfortable self-selected level. Participants were asked to press either the left or the right mouse button corresponding to the side the target was presented (left mouse click for left ear lion roar). The background sounds resembled a jungle environment (e.g., sounds of running water and various species of frogs, insects, and birds). The auditory target was presented randomly to discourage temporal approximation.

Risk perception pictures. Eleven photos of cycle ways; both trail and road, of local intersections or trails were used to assess perceived risk when cycled.. The cycle ways differed in illumination (day or night), their degree of traffic congestion, and steepness (Appendix E).

Risk perception questions. Participants were presented with 11 pictures of cycle ways as described above. Andrews and Gatersleben (2010) developed questions to measure danger for natural environments:

1. How likely do you think it is that you could come to harm cycling through this environment?
2. How severe are the dangers you could potentially face cycling through this environment?
3. How well do you think you could control any potential dangers while cycling in this environment?

Participants were asked to rate the pictures, based on the three questions, on a scale from one (being not very likely), to seven (very likely).

NASA TLX. The NASA TLX questionnaire used in the previous was employed.

7.3.3 Procedure

Control group. The control group was instructed to sit and listen to the jungle sounds with lion growls but they were not required to monitor the lion growls or respond to the sound stream in any way.

Cognitive fatigue group. The experiment group were instructed to complete the tracking and lion growl tasks.

Regardless of experimental condition, all participants completed a 5-minute simultaneous tracking and lion growl monitoring practice trial. This was used to familiarise participants with the vigilance task requirements should they be assigned to it and to make

the overall time identical to the control group. Both experimental and control conditions were 20 minutes. Participants were randomly assigned to either the control or cognitive fatigue group.

Upon completion of the prescribed task, (either control or cognitive fatigue) participants completed the risk perception questions for all 11 pictures.

7.4 Results

All participants answered the three risk questions for each picture. From this an average score (across pictures) was calculated for each question per person. Kolmogorov-Smirnov and Shapiro-Wilk normality tests were not statistically significant for picture groups in fatigue and not fatigued groups, $p > .05$. An independent t-test was used to compare the control group with the cognitive fatigue group. Participants in the cognitive fatigue group rated the cycle-ways as more risky than the control group for question 1 relating to danger (How likely do you think it is that you could come to harm cycling through this environment?), $t(56) = -2.21$, $p = .031$, but not for questions 2, (How severe are the dangers you could potentially face cycling through this environment?), $t(56) = -.46$, $p = .65$, or question 3, (How well do you think you could control any potential dangers while cycling in this environment?), $t(56) = -.11$, $p = .99$.

Means, standard deviations and 95% confidence intervals for differences between the control group and the cognitive fatigue group for each question are reported in Table 7.3.

Question	Group	Number	Mean (M)	Standard deviation (SD)	95% CI (lower, upper)
1	Control	29	4.55	1.17	-1.11, -0.54
	Fatigue	29	5.13	0.80	
2	Control	29	5.32	1.00	-0.57, 0.36
	Fatigue	29	5.43	0.70	
3	Control	29	3.67	0.97	-0.57, 0.56
	Fatigue	29	3.67	1.17	

Table 7.3: Means (M), standard deviation (SD) and CI for each question for the three pictures.

7.5 Discussion

As expected the participants in the cognitive fatigue group rated the pictures as more risky than the control group. However, this was true only for question one (How likely do you think it is that you could come to harm cycling through this environment) relating to danger. Question two (How severe are the dangers you could potentially face cycling through this environment) relating to fear and question three (How well do you think you could control any potential dangers while cycling in this environment) relating to preference were not significantly different from the non-fatigue group. The questions probe individual's perception of danger, and it could be that cognitive fatigue results in a greater assessment of danger in situ based on the assessment and cognitive state.

The results seem intuitive; as participants become fatigued it makes little sense to carry out physical tasks that may require great strength and endurance. Some of the pictures included very congested intersections with dense traffic that could be quite dangerous on a bike. This could be analogous to being less likely to risk venturing out to be eaten by a predator while you're tired because your chances of escape are less.

According to Slovic the more unknown and dreadful a situation the higher the perceived risk, meaning the less perceived control participants have over a potentially injurious or unpleasant situations the more risky they will rate it(Slovic et al., 2005). This is interesting to note for our results, there was no difference between the fatigued and control groups in their rated fear and preference, which may suggest that participants believed their chances of being hurt or killed was not up to them. If this was the case then it is interesting that when they were not fatigued they were more likely to take this risk than when they were fatigued. This interesting finding adds to risk perception theory, where state of mind effects the perception of risk. It also appears that the ability to control risk perception is not dependent on fatigue in this instance. Other human states have been shown to affect risk perception; as we know mood and gender differences are apparent (Gustafson, 1998; Johnson & Tversky, 1983). We can now add cognitive fatigue to the greater picture of our understanding of risk perception and how it can be manipulated. Investigating how various physical activities affect risk perception is pursued next.

Chapter 8 - Risk Perception and subjective flow states before and after the Queenstown marathon

8.1 Abstract

Subjective measures were taken from full and half marathon runners, before and after the Queenstown marathon. Participants volunteered to fill out a questionnaire rating their risk perception of cycle-ways before running, and then after running. They viewed 11 pictures of cycle-ways and answered three questions about those pictures. The three questions were;

1. How likely do you think it is that you could come to harm cycling through this environment? 2. How severe are the dangers you could potentially face cycling through this environment? 3. How well do you think you could control any potential dangers while cycling in this environment? The after running group also received a NASA-TLX and a subjective flow state questionnaire. Averages of each question were calculated of the 11 pictures. The full and half marathon runners results were combined and the after running group rated the pictures as more risky than the before running group. The pictures were not rated as more risky in the after compared to before groups when the full and half marathon groups were analysed separately. Removing question three (because it asks about control of risk) meant the full marathon group rated the pictures as riskier than the half marathon group. NASA-TLX results for mental and physical fatigue showed the marathon group rated their run as more physically and mentally tiring than the half marathon group. Interestingly both groups rated their mental fatigue as significantly higher than their physical fatigue. The short flow state scale was rated highly by all participants ($M=4.4$) on a scale from 1-5, suggesting a 'flow state' was experienced by most. The full marathon group rated themselves significantly higher on the scale than the half marathon runners. The authors suspect that this might be due

to the mental fatigue of full marathon runners leading them have depleted cognitive resources and in turn adopt a resource conservative mental state that presents as a flow state feeling. The questionnaires show with more fatigue, risk perception increases, that subjective mental fatigue is greater than physical fatigue in the full and half marathons and that fatigue and reports of flow state increase in the full marathon group when compared to the half marathon group. These results reflect the role of cognition in endurance physical tasks and fatigue. Continuing with future experiments along this theme, a physical risk of falling (leap of faith) could be completed after a cognitively fatiguing task to directly measure physical risk perception.

8.2 Introduction

This experiment builds on the work of the previous experiment, where cognitive fatigue was found to increase participants' perception of risk. Participants in this previous experiment were stationary and not involved in physical activity. Therefore this experiment analyses the effect of an endurance physical activity on risk perception. We know that mental fatigue creates increased risk perception of cycle-ways from the previous experiment and we know that physical activity is mentally fatiguing, therefore an endurance physical task should create increased perceptions of risk also. We expect to see lower ratings of the risk of cycle-way pictures before compared to after an endurance activity. We also expect the difference between before and after risk assessments to be greater following a full than half marathon.

8.3 Method

8.3.1 Participants

Participants were endurance runners participating in the Queenstown half or full marathon, in Queenstown New Zealand (Figure 8-1). Ages ranged from 21 to 45 ($M = 31.02$, $SD = 6.5$), participation was voluntary. Respondents were 144 marathon and half marathon runners. 51 responded for the before half marathon, 54 after half marathon, 27 before full marathon and 12 after full marathon.



Figure 8-1: Course overview

8.3.2 Materials

Questionnaires containing three questions that asked participants to rate the riskiness of pictures of cycle-ways were handed out. The post marathon questionnaire also included a flow state questionnaire and NASA-TLX (Appendix D, E, F). The short flow state scale (S FSS) asks one question for each flow dimension. There are nine dimensions, challenge-skill balance, merging of action and awareness, clear goals, unambiguous feedback, concentration on the task at hand, sense of control, loss of self-consciousness, transformation of time, autotelic experience.

8.3.3 Procedure

Before the marathon: Participants were given questionnaires asking them to rate how risky they perceived pictures of cycle-ways to be.

After the marathon: Participants were given the questionnaire asking them to rate how risky they perceived pictures of cycle-ways to be, the flow state questionnaire and the NASA-TLX.

Participants were canvased at the start line and surrounding areas of the full and half Queenstown marathon.

8.4 Results

8.4.1 Risk perception questionnaire

Kolmogorov-Smirnov and Shapiro-Wilk normality tests were not statistically significant for half, full and combined before and after results, all $p > .05$. Averages were calculated for the three questions for all pictures for each subject. The averages for each question were treated by a 2 (full vs. half marathon) X 2 (before after event) mixed ANOVA. The interaction effect was not significant, $F(1, 32) = 0.87, p = .77$. Therefore a paired samples t-test was used to compare the before and after scores for the three questions individually. The perception of risk was less in the combined before half marathon and full marathon condition ($M=4.81, SD=.87$) than the after, ($M=5.08, SD = 1.02$), $t(32) = -2.02, p = .052, M_{\text{difference}} = -.26, 95\% \text{ CI } [-.53, .003]$. However, there was no significant difference between the half marathon before ($M=4.87, SD=.97$. and after, ($M = 5.1, SD = 1.02$), $t(32) = -1.44, p = .161, M_{\text{difference}} = -.23, 95\% \text{ CI } [-.56, .1]$, or the full marathon before ($M=4.69, SD=.86$) and after scores ($M = 4.99, SD = 1.23$), $t(32) = -1.9, p = .067, M_{\text{difference}} = -.29, 95\% \text{ CI } [-.6, .02]$.

We also completed paired t tests on the averages of question 1 and 2 only because question 3 could be interpreted as a self-efficacy question as opposed to a perception of risk

question. Again the before group rated the pictures as less risky ($M=4.99$, $SD=.96$) than the after group did, ($M=5.32$, $SD=1.09$), $t(21)=-2.07$, $p=.051$, $M_{\text{difference}}=-.33$, 95% CI $[-.66, .002]$. There was no significant difference between the half marathon before ($M=5.09$, $SD=1.02$) and after, ($M=5.29$, $SD=1.13$), $t(21)=-1.04$, $p=.31$, $M_{\text{difference}}=-.19$, 95% CI $[-.59, .2]$, but excluding the third question exposed a significant difference in the full marathon before ($M=4.8$, $SD=.93$) and after scores ($M=5.49$, $SD=1.06$), $t(21)=-4.42$, $p=.000$, $M_{\text{difference}}=-.69$, 95% CI $[-1.01, -.37]$.

8.4.2 Flow state

A subjective flow state score was found for each subject by averaging ratings across all 9 questions. The maximum possible score is 5. Next we compared the half marathon averages with the full marathon averages using a t-test which showed participants in the full marathon subjectively rated a higher flow state ($M=4.74$, $SD=.19$) than the half marathon group ($M=4.19$, $SD=.27$), $t(11)=-5.75$, $p=0.00$, $M_{\text{difference}}=-.55$, 95% CI $[-.77, -.34]$.

8.4.3 NASA – TLX

We compared the subjective mental and physical fatigue ratings for the half and full marathon groups. The marathon group rated their mental fatigue ($M=93.33$, $SD=14.97$) higher than the half marathon group ($M=59.17$, $SD=13.79$), $t(11)=-5.79$, $p=0.00$, $M_{\text{difference}}=-34.17$, 95% CI $[-47.15, -21.19]$. The marathon group also rated their subjective physical fatigue ($M=87.5$, $SD=15$) as higher than the half marathon group ($M=57.92$, $SD=26.84$), $t(11)=-4.66$, $p=0.01$, $M_{\text{difference}}=-29.58$, 95% CI $[-43.56, -15.6]$. It is interesting to note that both groups rated mental fatigue higher than physical fatigue. It also confirms that the full marathon was perceived as more tiring than the half marathon and explains why the full marathon condition perceives a higher risk than the half marathon group.

8.5 Discussion

There was no statistically significant interaction between the before and after marathon running risk perception of cycle-ways. However, participants rated the pictures of cycle-ways as less risky before the full marathon than the group after the full marathon suggesting that physical and or mental fatigue has some impact on risk perception. There was no significant difference before and after running when the half marathon and full marathon groups were analysed separately. This may have been due to a small sample size but it could also be due to question three questioning self-efficacy as opposed to risk perception. Therefore, we analysed the same averages excluding the results from question three. There was a significant difference before and after in the combined and the full marathon groups but not in the half marathon group. Two different scenarios generated significant differences in fatigued groups to not fatigued groups. There were also differences in perceptions of fatigue, interestingly mostly mental as opposed to the expected physical fatigue. The flow state questionnaire showed most participants reached a 'flow state' during their run. While these results are somewhat inconclusive, taken with the results from chapter seven, it appears that cognitive fatigue and or physical fatigue has an impact on risk perception.

Subjective flow states were close to five (the highest rating) with a mean of 4.3. Also, participants in the marathon group gave higher ratings than the half marathon group. This means runners in the marathon believed themselves to be in more of flow state than those in the half marathon group. Flow states could be related to a type of cognitive 'automatic' mode. Marathons require the same movement on flat ground for between 3-5 hours, during this time resources may be managed conservatively to avoid fatigue and gives the runner a feeling of lost time, automaticity, and flow as the other brain regions are dulled due to less available resources. Fatigue seems to explain why the marathon runners were in more of a flow state

than the half marathon runners. This ability to accommodate and reduce fatigue has a performance effect because we know that the more automated movement can be, the better one performs according to flow state and RAH theory (Dietrich & Audiffren, 2011).

Results from the NASA TLX for subjective mental and physical fatigue showed the full marathon was more tiring than the half marathon. The marathon was rated significantly higher in both mental and physical fatigue and interestingly mental fatigue was rated higher than physical fatigue in both the full and half marathons. Taking the subjective flow state and NASA TLX measures into account it is reasonable to suggest that marathon running is more tiring than half marathon running and that it is more mentally tiring than physically tiring.

Future experiments to expand on the ideas of the last two chapters could include a physical task that induces fear, a type of rock climbing or leap of faith after a cognitively fatiguing task, which would test if the risk perception of a physical task is different to viewing the cycle-way pictures. Including a cycle task instead of rating pictures could also be explored however this would be bound by potential ethical constraints if putting participants in risky situations. Using a more robust measure of risk perception, consistent with the literature that can define different types of risk may also be interesting.

Chapter 9

9.1 Overview of Experiments

9.1.1 Chapter Two

Chapter two investigated the dual task effects running on a flat outdoor track has on a working memory task. It expanded on work previously investigated by Blakely and colleagues (2015) where dual task interference was found, but the cognitive task included a concerning visual response (button press) which could have led to peripheral interference. Participants in this experiment reported their responses verbally and were recorded to play back later, which limited peripheral interference. The results were similar to that of the original experiment; running distance followed a declined trend as the task became more difficult. There is competition for resources between these two tasks and running is not prioritised which has implications for many physical professions and sports. Accuracy on the working memory counting task also showed similar trends, the low load task was not significantly affected by running however the high load task was. This is likely due to an increase in cortical arousal which assists the low load condition but the interference eventually becomes too great in the high load condition.

9.1.2 Chapter Three

Chapter three expanded on the findings in chapter two by using the same counting task with a dual kayak task. The same dual-task paradigm was used and generated similar results. There were detrimental effects to counting task performance in the high load condition only. This pattern suggests there is a mechanism assisting cognitive performance that makes counting the low load task while completing a physical task as easy as completing the low load task as a single task. There were less correct responses for the dual high load

task than the single high load task which suggests there is a point at which the cognitive demand for resources is overwhelmed, again this is similar to results in chapter two.

Kayaking performance showed a familiar trend also; as the counting task became more difficult, the kayak speed decreased. There was some difference between kayaking and running however; running results show a steady decline as tasks became more difficult but kayak speed appears to abruptly decrease in the low load condition and stay relatively consistent in the high load task. A maximum resource overload threshold may have occurred in the low load task which meant there was no more detriment possible in the high load task. It appears that having a cognitive task to perform at the same time as kayaking effects speed regardless of cognitive task complexity which is particularly useful for athletes in this field. The next step was to compare an anaerobic task to compare to these aerobic tasks, to gain some insight into the effects of cardiovascular intensity on brain cognition.

9.1.3 Chapter Four

The main aim of this experiment was to expand on the two previous experiments by using a more cognitively complex and anaerobic physical task: climbing. The counting task showed more of a decrement in the dual conditions than in the single, and more in the high load than in the low load. There were no significant differences in climbing performance observed between the dual and single conditions however there was a difference between low and high load distances. This prioritisation of climbing is likely due to one of the many attentional demands required of the sport; either planning, reaching, postural control, movement or fear of falling or all of the above, indicating contrary to the literature and previous experiments that rock climbing is unique in that participants prioritise this task over any other.

9.1.4 Chapter Five

Chapter five shifted focus somewhat to test the counting task in a laboratory setting in order to verify its generalisability. Coupling it this time with a basic arithmetic task, this experiment duplicated the design of the three previous experiments. The results were as expected; performance on the counting task became worse in the dual condition than in the single task condition for both high and low loads, and the number of correct basic maths equations decreased as the counting task became more difficult. This experiment gives us a comparison baseline, to compare with the physical tasks, the effect of the counting task in the dual task paradigm.

9.1.5 Chapter Six

A comparative analysis of the first four experiments is presented in chapter six. Overall the tasks appear quite similar with the exception of rock climbing. Rock climbing seemed to take priority over the tone counting task which is opposite to the other tasks. Why is rock climbing so taxing to cognitive resources? It appears that most parts of the rock climbing process require attention, reach process, movement planning, postural control and fear of falling. All of these factors slow down the climbing process and when participants are under time pressure there is no availability to complete other tasks. Certainly the fear of falling could be investigated in other contexts and sports to explore this further.

9.1.6 Chapter Seven

The analysis of dual cognitive physical task results shows how much of an impact cognition can have on physical performance and vice versa. It is well accepted that a mechanism in the pre frontal cortex may be responsible for the breakdown of processes concerned with volitional control. This decline over time seems indicative of fatigue and

there is support of this from a neuroergonomic perspective where EEG and fNIRS experiments show declining oxygenation as time on tasks increases. Fatigue also has an effect on consequent physical activity; several experiments outline a loss of endurance, stamina and technical skill as time goes suggesting that cognitive fatigue is responsible for loss in performance with time. Another potential reason for declined performance is risk perception, as fatigue increases a conservation model is applied and the amount of risk prepared to experience declines. This would certainly reduce performance. Chapter seven outlines a risk perception experiment; participants were divided into two conditions, one cognitive fatigue, and the other no cognitive fatigue and then rated the riskiness of cycle-ways. Participants in the cognitive fatigue group rated cycle-ways as more risky than the control group suggesting that mental fatigue makes us perceive cycle-ways as more risky. This would be consistent with the evolutionary theory that we make more conservative decisions when we're tired in order to avoid harm.

9.1.7 Chapter Eight

Chapter eight follows on from the risk perception experiment in chapter seven. This chapter reports an observational study as opposed to direct experimental manipulation. The reason for this was because the authors wanted to measure risk perception in a group of very physically fatigued persons, and marathon runners were an obvious fit. Results showed risk perception was greater after running than before and greater in the marathon runners than the half marathon runners but there was not statistically significant interaction between before and after, full and half marathon. Subjective ratings of mental and physical fatigue and flow states were also greater in the full marathon group. The authors theorise that feelings of flow state could be due to fatigue creating a limited resource allocation to certain areas (possibly PFC) in order to create automaticity in the motor cortex to perform motor function smoothly, this would account for a feeling of losing time for example. Future work on risk perception

and fatigue could explore the role of a risky physical task (leap of faith or rock climbing) with a cognitively fatiguing task.

Chapter 10

10.1 General Discussion

Tone counting performance summary (chapters 2, 3, 4, and 5): Tone counting performance was significantly worse in the dual task conditions than the single task conditions for the running, kayaking, climbing and maths experiments. When comparing the one count (low load) with the three count (high load) conditions, the running and kayaking were not different, but the climbing and maths tasks showed a significant difference. This means that all participants performed better when they were completing one task than two, so the dual task was effective. Running and kayaking showed no performance differences between low or high load tasks, meaning they put more effort into the counting task by not focusing on the running, or kayaking tasks. This theory is supported by the running, kayak performance data, as the task became more difficult, running and kayak performance got worse in a linear fashion. Remembering that participants were not prompted to focus more on either task but to do their best in both, participants have prioritised the cognitive task over the physical task, at least in part. According the MRT when resources are depleted, attention is divided based on some sort of prioritisation and in the case of running and kayaking it appears to be on the cognitive task. Another alternative is that cyclical, more automatic type physical activity is less demanding of the PFC and relies on caudal cortical areas, therefore not creating as much interference as a cognitively demanding physical task so additional effort isn't of as much consequence. However, vigilant attention, (monotonous, scanning tasks) show a marked decline in performance with time (Langner & Eickhoff, 2013). Vigilant attention therefore is maintained by an unsustainable resource which best describes the process of fatigue. If we consider the physical tasks of running and kayaking vigilant tasks, attention resources are required to maintain a constant pace and the cognitive task shares the

resource (central executive). Vigilance experiments, monitoring computer screens for targets while completing a working memory task, can show deteriorating effects after just 2 min (Helton et al., 2010).

The level of PFC demand correlating with task disruption seems reasonable given the climbing and maths task results. We know that two maths tasks will interfere with each other, potentially about as much as two tasks can, according to MRT. Climbing and maths shared similar results (comparatively) in the cognitive task, there was a difference between no load and load, and there was a difference between low load and high load. When we combine the climbing performance, where the physical task performance got worse as the load increased, it appears that climbing is creating additional interference to the cognitive task than the other physical tasks. The maths addition/subtraction task showed a decline in performance as task difficulty increased also, and we know that this task was designed for maximum cognitive interference and it is intriguing that the climbing task results are so similar. It provides support for the argument that climbing is heavily demanding of resources in the PFC. The next question lies in what specifically about climbing that creates this?

It could be argued that the fear of falling in rock climbing means participants prioritise the physical task over the cognitive one. To test this, we analysed the NASA TLX tension scale. Results showed that climbers were in fact more tense in the climbing condition than the seated, however when we analysed the maths data, it showed the same thing. Noting that the maths task was designed as a kind of control task to compare with the physical tasks, the evident difference in tension when comparing two seated tasks indicates participants generally found dual tasks more stressful than single. Another point worth noting is that kayaking requires balance to remain upright, and a fear of falling into the water in the types of boats the participants were paddling (racing boats that are very tippy) means this fear would have been present also. Falling into the Avon River (which is not a swimmable river)

versus fear of falling onto a padded matt would not be dissimilar, and indeed the kayaking tension results showed a difference in tension between the single and dual tasks also. It is still possible that the fear in rock climbers was greater than for the other tasks and certainly a specific anxiety questionnaire would provide more insight into what exactly creates more tension.

Ruling out emotion as the source of PFC interference, leaves complexity and possibly decision making as factors that create more interference in climbers than the other physical tasks. As outlined in the risk perception sections of this thesis, decision making is a complex, cognitively demanding activity reliant on the PFC (Slovic et al., 2005). The very point of rock climbing even on a man-made wall is to challenge the climber to make decisions about what will be the best foot and hand placement. Typically rock climbing is not a race or time dependent, so the climber can choose the holds at their leisure. This experiment placed them under significant time pressure to perform. This may have overwhelmed the decision making processes in the PFC of the climbers. Running and kayaking are somewhat cognitively demanding however the movement is repetitive, and mostly familiar especially in experts. Rock climbing is however novel, experienced climbers may have some mental schema that helps them predict good holds, but the placement of the holds are swapped around regularly, the position on the wall changed and each hold chosen then automatically changes how novel the next hold will be. The experiment was filmed and no participants chose the exact same holds for all three climbs. Therefore the dynamic nature of climbing means participants needed to assess and decide which holds were the most efficient in a limited amount of time. This is the most likely reason the climbing task had similar results when compared to a completely cognitively demanding task like the maths task, and is most consistent with MRT.

Physical task performance summary (chapters 2, 3, 4, and 5): Dual tasking affected running, kayak, and climbing distance, as well as maths performance. The trend was linear;

the more cognitive task demand, the less distance was covered. This evidence provides support showing the cognitively demanding element of physical activity. Muraven & Baumeister (2000) suggest findings like this could be due to the demanding suppressive effects of self-regulation; control over oneself, by oneself requires an attentional resource which is limited, and degrades with time (Muraven & Baumeister, 2000). Self-regulatory control or attention vigilance has been linked to regions in the prefrontal cortex, suggesting that even simple repetitive tasks require attentional resources (Langner et al., 2010). Certainly volitional control would account for the decline in physical performance in our experiments, where the cognitive load and subsequent cognitive resources required for that load increase the availability of resource to will oneself to maintain running, kayak or climbing speed deteriorates. It has been demonstrated that working memory tasks, negatively affect vigilance, and that the high cognitive resource demand vigilance places on resources creates a decrement, which is synonymous with our experiments (Helton & Russell, 2011). The physical activities in the experiments appear to be physically and mentally demanding, and maintaining a fast pace, without outside enforcement requires effort. This self-regulation interference, may explain the overall negative effect to the physical task when a cognitive task is added, making the athlete slow down.

Risk perception and fatigue summary (Chapters 7 and 8): Cognitive and physical fatigue was used to establish whether fatigue changes our perception of risk. The vigilance task in chapter 7 changed the participants' perception of risk when compared with the control group. We also found that marathon runners deemed the cycle-way pictures to be more risky after the marathon than before. It could be argued that a marathon uses significant amounts of self-regulation and is therefore a mentally fatiguing task which would account for the similar results to the vigilance task. The interesting part to note in the marathon study is that the effects of exercise appear to have remained even after the cessation of physical activity,

because others have found that cognitive function is restored immediately after a bout of physical activity (Dietrich & Audiffren, 2011). Certainly the results from these two studies imply lasting fatigue of the PFC, which resulted in a more conservative perception of risk.

The reason for an increased perception of risk in fatigued participants is likely due to the two tasks using similar amounts of processing resources. The vigilance or running task created cognitive fatigue, but the questionnaire was given immediately afterwards effectively continuing their cognitive work. The decision making required for immediate risk perception of this nature was as demanding on resources as the initial task. Although the MRT has not been specifically set out for use in risk perception research it can easily be applied. Going back to Mosso in the 1800's, not only is the thought of participating in a physical task after a mentally strenuous day not appealing, it may also change the perception of safety. Cyclists commuting to work may find it enjoyable, but on their way home it may be more stressful (tiring) if they view the task as more risky than at the beginning of the day, or if they hadn't worked that day. It is evident that mental fatigue changes the risk perception of cycle-ways and this is likely due to depleted processing resource.

According to Wickens (2002) MRT, dual task interference decrements increase depending on the amount of stages, codes, modalities and channels of visual information that they share. Applying the MRT to the results of the experiments, there is overlap in almost all experiments for the stages of processing dimension. The multiple resource model, also relates to demand, resource overlap and allocation in order to explain dual task effects. The modalities are mostly spatial for the physical tasks and auditory for the counting task so these are unlikely to use the same resource. Responses are vocal and verbal and therefore rules out any overlap with the manual spatial responses. This breakdown demonstrates that there is very little overlap in in dual resources other than the stages or processing, and likely the overlap in these dual tasks lies in the cognition phase. The cognitive demand required for

running, volitional control (spatial) exceeds resource availability because it is being taxed by the cognitive task, working memory (verbal). This appears to be the best fit to explain the results from these experiments.

10.2 Practical Applications

Occupations involving physical tasks and sports people alike can apply the findings of this research. It is interesting to note that cyclical activities in ecological environments when coupled with another task, are performed significantly worse. These results can be applied specifically to armed forces, police, fire fighters and even some construction roles. The cognitive task is also affected negatively, although there is no difference if the task is hard or easy. Certainly complex physical tasks should be completed without another dual task as evidenced by the rock climbing experiment and could be applied to search and rescue occupations. Results from the risk perception studies are applicable to sports people, when they are tired they will likely take a more conservative approach and slow down. This is evident in kayaking, as a paddler becomes more tired they choose the ‘chicken line’ down a rapid as opposed to the ‘fast line’. Solutions to these problems are to prevent fatigue or to complete one task at a time and be aware of the heightened perception of risk.

10.3 Limitations and Future Research

Valuable future research would explore fatigue and lengthening the mental and physical tasks to establish if the effects worsen with time. Also using brain imaging like near functional near-infrared spectroscopy (fNIRS) would give specific real time details about what happens while dual physical, cognitive tasks are performed. A leap of faith (risky) task could be coupled with a prior vigilance or physical task in order to check the results of the risk perception studies. It would be interesting to check if subjective reporting (questionnaire) of willingness to take a risk was synonymous with the physical act.

During whole body exercise the mind goes into autopilot or a flow state which is run by the implicit system (Dietrich). Cozato (2014) and colleagues tested runners using convergent and divergent thinking tasks. Convergent thinking relies heavily on the top down process in the search for constrained responses and just one answer. Whereas divergent thinking involves searches for many and broad solutions to problems and utilises little top down processes, an example of which is brainstorming. These two processes are thought to be drawn from different areas of executive function and it is suggested exercise affects the two differently. In a group of unfit participants both convergent and divergent thinking was negatively affected by exercise, however fit individuals showed increased performance in divergent thinking (Cozato et al 2014). It may be that divergent thinking is what is effecting rock climbing ability and generating results similar to the maths control group. It is possible to distinguish this with a rock climbing experiment where there is effectively only one option for holds for each move. This would remove the choice element and it would be predicted that rock climbers would perform better in this situation than when they have several choices that they have to weigh up in a limited time frame. Future rock climbing research needs to distinguish if the poor performance of rock climbers was due to fear of falling, hold decision making and postural control, or volitional control.

Flow state theories of running appear to be evident in our results. However, the authors contest that flow states are described in the RAH model as the implicit phase of exercise where movement is automatic and not impacted by explicit thought. The movement is therefore free and flowing. Flow state research can therefore be folded into the RAH model and experiments could be investigated where runners have their 'flow' interrupted and are required to practice explicit actions. fNIRS would also be useful in the investigation of this phenomena because it has been suggested that as the PFC is depleted of resource, the feeling of implicit movement or flow state presents itself (Dietrich & Audiffren, 2011).

Thought probe research would be another interesting way to investigate thought processes during particularly long bouts of exercise, an accurate recording device could be attached to very long distance athletes to investigate their cognitive abilities. Mapping several athletes over the course of ultra-marathons (100km +) or Godzone (5days non-stop +) would certainly provide insight into cognitive processes at such levels of fatigue and resource depletion.

10.4 Concluding Statement

These dual cognitive, physical task experiments produced some interesting results for dual task theory. All were affected negatively by the dual task, in the cognitive and physical task performance. Interestingly the rock climbing seemed to have more of a detriment to the other tasks and it would be reasonable to assume this is due to the cognitively challenging nature of the sport. Participants viewed cycle-ways as more risky when they were cognitively fatigued which means risk perception is changeable based on mental state. MRT may be the best explanation for the results so far, volitional control and the working memory task interfere with each other, and cognitive fatigue changes our decision making abilities, which shows an overlap of resources resulting in depleted performance.

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Appendix A

PAR

Physical Activity Rating (PA-R)

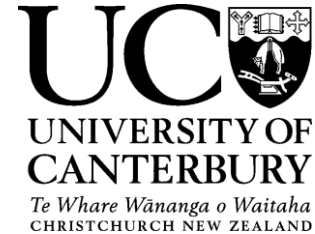
Please circle the number that best describes your overall level of physical activity for the previous month:

- 0 Avoid walking or exertion, e.g. always use the elevator, and drive when possible instead of walking.
- 1 Light activity: Walk for pleasure, routinely use stairs, occasionally exercise sufficiently to cause heavy breathing or perspiration
- 2 Moderate activity: 10 to 60 minutes per week of moderate activity, such as golf, horseback riding, table tennis, bowling, weight lifting, yard work, cleaning house, walking for exercise
- 3 Moderate activity: Over 1 hour per week of moderate activity as described above
- 4 Vigorous activity: run less than 1 mile per week or spend less than 30 minutes per week in comparable activity such as running or jogging, lap swimming, cycling, rowing, aerobics, skipping rope, running in place, or engaging in vigorous aerobic-type activity such as soccer, basketball, tennis, racquetball, or handball.
- 5 Vigorous activity: run 1 mile to less than 5 miles per week, or spend 30 minutes to less than 60 minutes per week in comparable physical activity as described in 4 above.

- 6 Vigorous activity: run 5 miles to less than 10 miles per week or spend 1 hour to less than 3 hours per week in comparable physical activity as described in 4 above
- 7 Vigorous activity: run 10 miles to less than 15 miles per week or spend 3 hours to less than 6 hours per week in comparable physical activity as described in 4 above
- 8 Vigorous activity: run 15 miles to less than 20 miles per week or spend 6 hours to less than 7 hours per week in comparable physical activity as described in 4 above
- 9 Vigorous activity: run 20-25 miles per week or spend 7 to 8 hours per week in comparable physical activity as described in 4 above
- 10 Vigorous activity: run over 25 miles per week or spend over 8 hours per week in comparable physical activity as described in 4 above

Appendix B

Information and Consent Forms



Psychology Department

Email: megan.blakely@pg.canterbury.ac.nz

Information Sheet

My name is Megan Blakely, I am completing my PHD on the cognitive effects of exercise. This experiment is investigating the cognitive effects of whole body exercise using a counting task. You will be asked to complete three, five minute runs while you complete the counting task. You will also be asked to complete two counting tasks while seated. The distance you run and the accuracy on the counting task will be measured and recorded. It is expected that it will take an hour for you to complete all the tasks. The running track is a flat loop. You will be required to wear a helmet for your protection which is also part of the listening apparatus.

Participation is voluntary and you have the right to withdraw at any stage without penalty. If you withdraw, I will remove all information relating to you. You will have to request this within two months of participation or your results become part of the thesis. The results of the project may be published, but you can be assured that data gathered in this research will be treated confidentially. To ensure anonymity and confidentiality, your name will be replaced by a number and will not be recorded with any of the results. The data will be securely stored on a password protected laptop. The data will only be used to produce statistical analysis for this project and may be used for continuing research of the same nature. A thesis is a public document and will be available through the UC

Library. You may receive a copy of the project results by contacting the researcher at the conclusion of the project.

The project is being carried out as part of a PHD in Psychology by Megan Blakely under the supervision of Deak Helton. He will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz). If you agree to participate in the study, you are asked to complete the consent form and return to the researcher.

Psychology Department

Email: megan.blakely@pg.canterbury.ac.nz

Consent Form

I have been given a full explanation of this project and have had the opportunity to ask questions.

I understand what is required of me if I agree to take part in the research I understand that participation is voluntary and I may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.

I understand that any information or opinions I provide will be kept confidential to the researcher and that any published or reported results will not identify the participants. I understand that a thesis is a public document and will be available through the UC Library.

I understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after five years.

I understand the risks associated with taking part and how they will be managed.

I understand that I am able to receive a report on the findings of the study by contacting the researcher at the conclusion of the project.

I understand that I can contact the researcher, Megan Blakely at megan.blakely@pg.canterbury.ac.nz or supervisor Deak Helton for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)

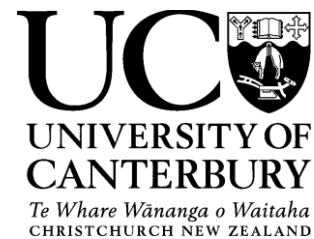
By signing below, I agree to participate in this research project.

Name:

Date:

Signature:

Please return your form to the researcher.



Psychology Department

Email: megan.blakely@pg.canterbury.ac.nz

Fitness Test Instructions - Please read and follow these instructions prior to your fitness test.

Prior to completing the study, you will be asked to complete a fitness test. This is a field test that measures your VO₂max reliably. The test is performed on a 400 m track and the objective is to jog for 1 mile at a comfortable pace. The mile jog should take longer than 8min for males and 9min for females. Your heart rate, height and weight will also be recorded.

Please adhere to the following steps before your fitness test. Avoid vigorous exercise the day before. Sleep for at least 7 hours on the night prior. Please refrain from alcohol consumption the night before and avoid caffeine or nicotine at least 3 hours before testing. To avoid dehydration please drink 35ml of water per kilogram of body weight the day before the test.

Pre-test Checklist

Please tick to confirm the following protocols were adhered to

Slept for at least 7 hours last night ☐

Refrained from alcohol consumption last night ☐

Avoided vigorous exercise yesterday ☐

Avoided caffeine and nicotine at least 3 hours before testing ☐

Consumed 35ml of water per kilogram of body weight yesterday ☐

Are you feeling generally well? ☐

Name:

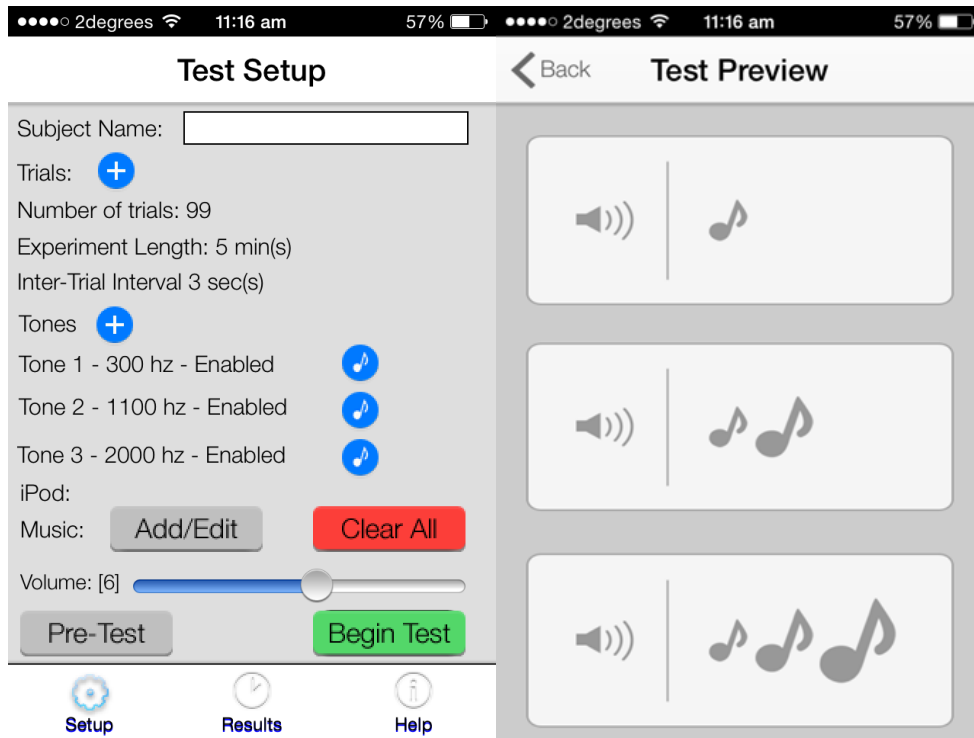
Date:

Signature:

Please return your form to the researcher.

Appendix C

Smart phone interface



Appendix D

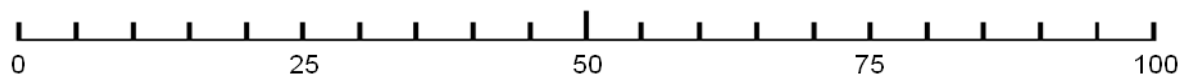
NASA TLX

MALE or FEMALE (circle one)

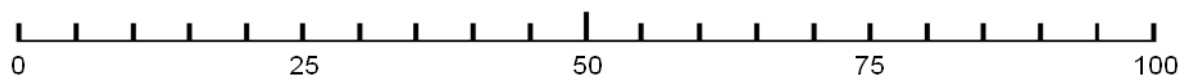
Age: _____

For the following items use the response scale below the item by circling the vertical line closest to your answer; the scale goes from 0 (**very low**) to 100 (**very high**). These questions refer to your experience during the task.

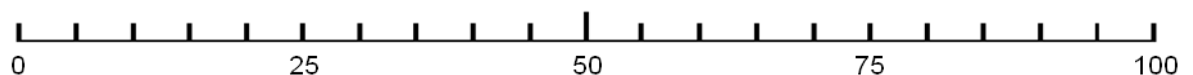
1. **Mental Demand** - How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)?



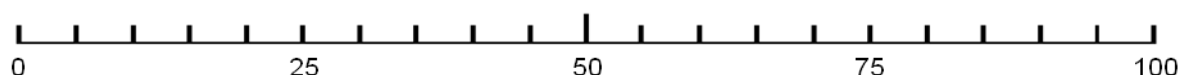
2. **Physical Demand** - How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)?



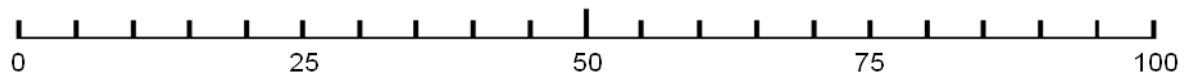
3. **Temporal Demand** - How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred?



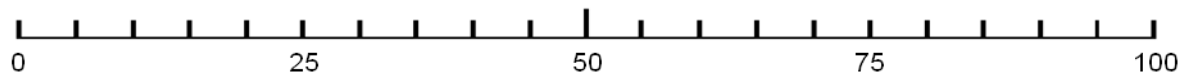
4. **Emotional Demand** – How emotionally demanding was the task?



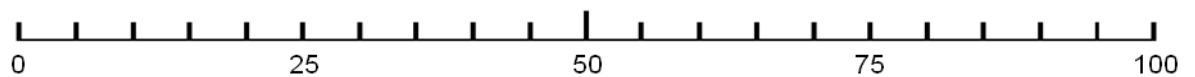
5. **Performance Monitoring Demand** – How much did the task require you to monitor your performance?



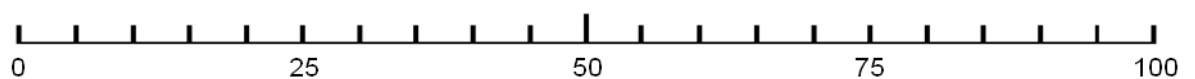
6. **Effort** – How hard did you have to work to accomplish your level of performance?



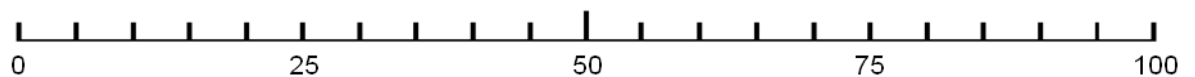
7. **Physical Fatigue** – How physically exhausted and tired did you feel?



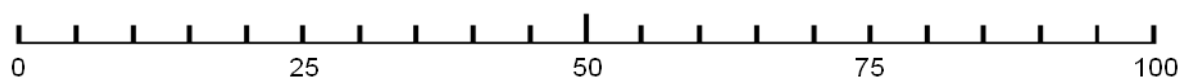
8. **Mental Fatigue** – How mentally exhausted and tired did you feel?



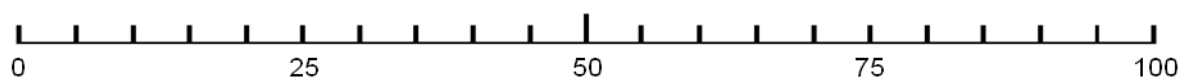
9. **Tense** – How tense or anxious did you feel?



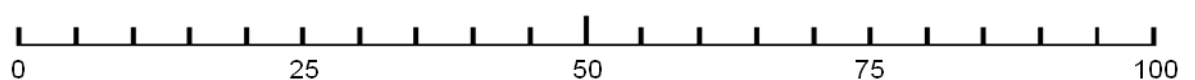
10. **Unhappy** – How unhappy did you feel?



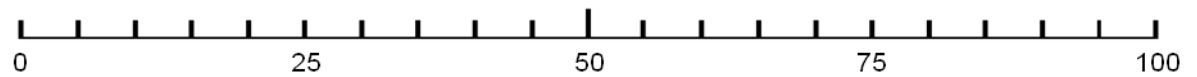
11. **Motivation** – How motivated were you to do well?



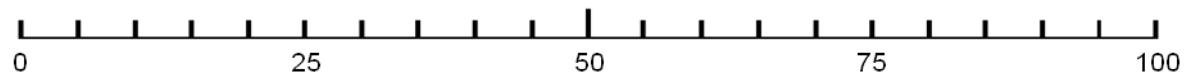
12. **Task Interest** – How interesting was the task?



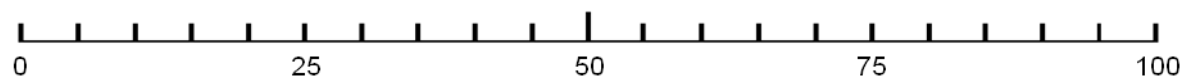
13. **Self Related Thoughts** - How much did you think about yourself?



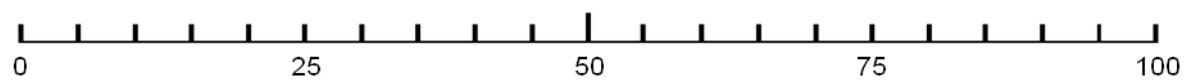
14. **Concentration** – How focused on the task were you?



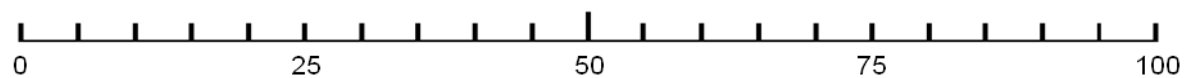
15. **Confidence** – How confident were you during the task?



16. **Task Related Thoughts** - How much did you think about the task?



17. **Task Unrelated Thoughts** – How much did you think about something other than the task?



Appendix E

Risk Perception Questionnaire

Age: ____ years

Gender:

Male

Female

Event:

Half Marathon

Full Marathon

Do you cycle regularly?

Yes

No

How many times a week? _____

Instructions

Indicate the degree to which you disagree or agree with each of the statements below by circling **one** number from 1 to 7. Please do not spend too much time on any one item



How likely do you think it is that you could come to harm cycling through this environment?

strongly	1	2	3	4	5	6	7	strongly
disagree								agree

How severe are the dangers you could potentially face cycling through this environment?

	1	2	3	4	5	6	7	strongly
								agree
strongly								
disagree								

How well do you think you could control any potential dangers while cycling in this environment?

	1	2	3	4	5	6	7	strongly agree
strongly disagree								



How likely do you think it is that you could come to harm cycling through this environment?

strongly disagree	1	2	3	4	5	6	7	strongly agree
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How severe are the dangers you could potentially face cycling through this environment?

strongly disagree	1	2	3	4	5	6	7	strongly agree
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How well do you think you could control any potential dangers while cycling in this environment?

strongly disagree	1	2	3	4	5	6	7	strongly agree
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How likely do you think it is that you could come to harm cycling through this environment?

strongly	1	2	3	4	5	6	7	strongly
disagree								agree

How severe are the dangers you could potentially face cycling through this environment?

	1	2	3	4	5	6	7	strongly agree
strongly disagree								

How well do you think you could control any potential dangers while cycling in this environment?

	1	2	3	4	5	6	7	strongly agree
strongly disagree								



How likely do you think it is that you could come to harm cycling through this environment?

strongly	1	2	3	4	5	6	7	strongly
disagree								agree

How severe are the dangers you could potentially face cycling through this environment?

strongly
disagree

1 2 3 4 5 6 7

strongly
agree

How well do you think you could control any potential dangers while cycling in this environment?

strongly
disagree

1 2 3 4 5 6 7

strongly
agree



How likely do you think it is that you could come to harm cycling through this environment?

strongly	1	2	3	4	5	6	7	strongly
disagree								agree

How severe are the dangers you could potentially face cycling through this environment?

	1	2	3	4	5	6	7	strongly agree
strongly disagree								

How well do you think you could control any potential dangers while cycling in this environment?

	1	2	3	4	5	6	7	strongly agree
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How likely do you think it is that you could come to harm cycling through this environment?

strongly	1	2	3	4	5	6	7	strongly
disagree								agree

How severe are the dangers you could potentially face cycling through this environment?

1	2	3	4	5	6	7	strongly
---	---	---	---	---	---	---	----------

agree

strongly

disagree

How well do you think you could control any potential dangers while cycling in this environment?

1

2

3

4

5

6

7

strongly
agree

strongly

disagree



How likely do you think it is that you could come to harm cycling through this environment?

strongly	1	2	3	4	5	6	7	strongly
disagree								agree

How severe are the dangers you could potentially face cycling through this environment?

	1	2	3	4	5	6	7	strongly agree
strongly disagree								

How well do you think you could control any potential dangers while cycling in this environment?

	1	2	3	4	5	6	7	strongly agree
strongly disagree								



How likely do you think it is that you could come to harm cycling through this environment?

strongly	1	2	3	4	5	6	7	strongly
disagree								agree

How severe are the dangers you could potentially face cycling through this environment?

	1	2	3	4	5	6	7	strongly agree
strongly disagree								

How well do you think you could control any potential dangers while cycling in this environment?

	1	2	3	4	5	6	7	strongly agree
strongly disagree								



How likely do you think it is that you could come to harm cycling through this environment?

strongly	1	2	3	4	5	6	7	strongly
disagree								agree

How severe are the dangers you could potentially face cycling through this environment?

1 2 3 4 5 6 7 strongly agree

strongly disagree

How well do you think you could control any potential dangers while cycling in this environment?

1 2 3 4 5 6 7 strongly agree

strongly disagree



How likely do you think it is that you could come to harm cycling through this environment?

strongly disagree	1	2	3	4	5	6	7	strongly agree
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How severe are the dangers you could potentially face cycling through this environment?

strongly disagree	1	2	3	4	5	6	7	strongly agree
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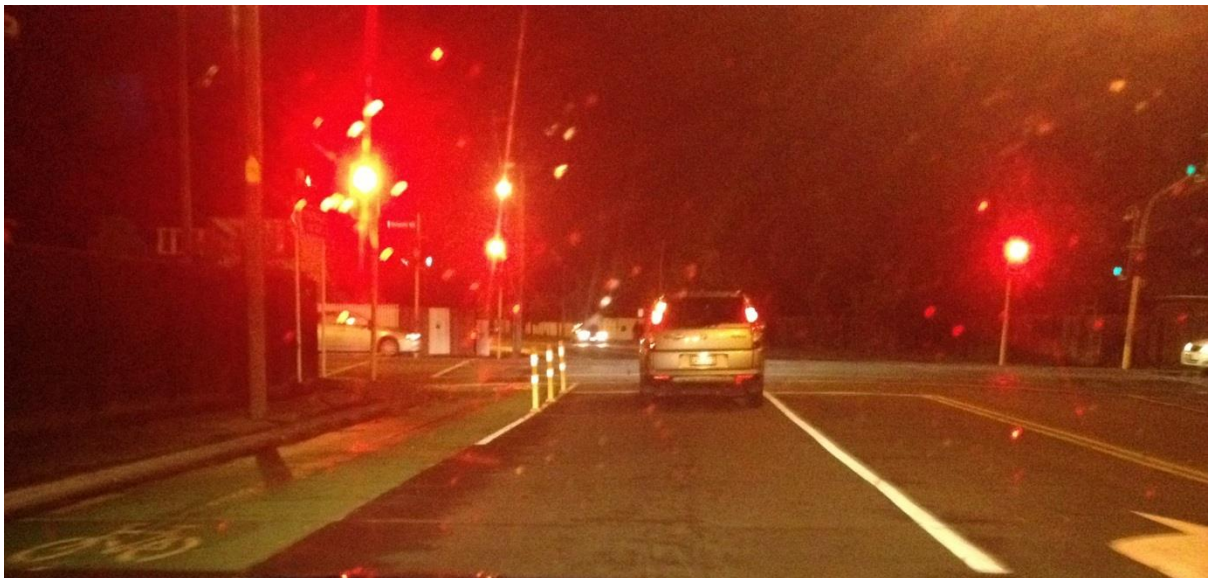
How well do you think you could control any potential dangers while cycling in this environment?

1	2	3	4	5	6	7	strongly
---	---	---	---	---	---	---	----------

agree

strongly

disagree



How likely do you think it is that you could come to harm cycling through this environment?

strongly disagree	1	2	3	4	5	6	7	strongly agree
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How severe are the dangers you could potentially face cycling through this environment?

strongly disagree	1	2	3	4	5	6	7	strongly agree
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How well do you think you could control any potential dangers while cycling in this environment?

strongly disagree	1	2	3	4	5	6	7	strongly agree
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Appendix F

Short Flow State Scale (SFSS)

Please answer the following questions in relation to the event or activity you have just completed. These questions relate to the thoughts and feelings you may have experienced while taking part in the activity. There are no right or wrong answers. Think about how you felt during the event/activity, then answer the questions using the rating scale below. For each question, circle the number that best matches your experience.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
1 I felt I was competent enough to meet the demands of the situation	1	2	3	4	5
2 I did things spontaneously and automatically without having to think	1	2	3	4	5

3 I had a strong sense of what I wanted to do	1	2	3	4	5
4 I had a good idea about how well I was doing while I was involved in the activity/task	1	2	3	4	5
5 I was completely focused on the task at hand	1	2	3	4	5
6 I had a feeling of total control over what I was doing	1	2	3	4	5
7 I was not worried about what others may have been thinking of me	1	2	3	4	5
8 The way time passed					

seemed to be different from normal	1	2	3	4	5
9 I found the experience extremely rewarding	1	2	3	4	5